MISSOURI DEPARTMENT OF NATURAL RESOURCES
Missouri Geological Survey

US Army Corps of Engineers

MISSOURI WATER RESOURCES PLAN

Combined Technical Workgroup Meeting

Nov 28, 2018, 9:00 a.m. to 12:00 p.m.

Missouri Water Resources Plan

Agenda

9:00	Introductions
9:05	Quantification of Planning Scenario Drivers
9:30	Scenario Planning – Water Supply Shortages
10:50	BREAK
11:00	Groundwater Budget Update
11:30	Infrastructure Update
12:00	Adjourn

MISSOURI WATER RESOURCES PLAN

Proposed Scenarios for Missouri Plan

Missouri Planning Scenarios

Scenario	M&I Demands	Ag Demands	Climate	Water Treatment Level	Supply Constraints	Reservoir Regulations
Business-As-Usual	• Baseline M&I demands • Baseline Rural demands	• Med Ag irrigation • Med Ag processing	• Historical temperatures • Historical precipitation	• Existing water treatment levels	• No water supply constraints	• No re-allocation of USACE reservoirs for supply • Existing permitting process for new reservoirs
Strong Economy/ High Water Stress	• High M&I demands • Higher Rural demands	• High Ag irrigation • Med-High Ag processing	• Hotter temperatures • Lower rainfall	• High increase in water treatment levels	• Interstate diversions out of Missouri River Basin • Limitations on GW (select areas) • Prolonged supply disruption on River intakes	• Limited re-allocation of USACE reservoirs for supply • Streamlined permitting process for new reservoirs
Substantial Agricultural Expansion	• Baseline M&I demands • Baseline Rural demands	• Med Ag irrigation • Highest Ag processing	• Warmer temperatures • Greater rainfall	• Moderate increase in water treatment levels	• Interstate diversions out of Missouri River Basin • Limitations on GW (select areas)	• Limited re-allocation of USACE reservoirs for supply • Existing permitting process for new reservoirs
Weak Economy/ Low Water Stress	• Low M&I demands • Baseline Rural demands	• Med Ag irrigation • Med Ag processing	• Warmer temperatures • Greater rainfall	• Existing water treatment levels	• No water supply constraints	• No re-allocation of USACE reservoirs for supply • Existing permitting process for new reservoirs

Quantification of Scenario Planning Drivers

Scenario Drivers

- M&I Demands
- Agricultural Demands
- Climate
- Supply Constraints
- Water Treatment Levels
- Regulations

MISSOURI WATER RESOURCES PLAN

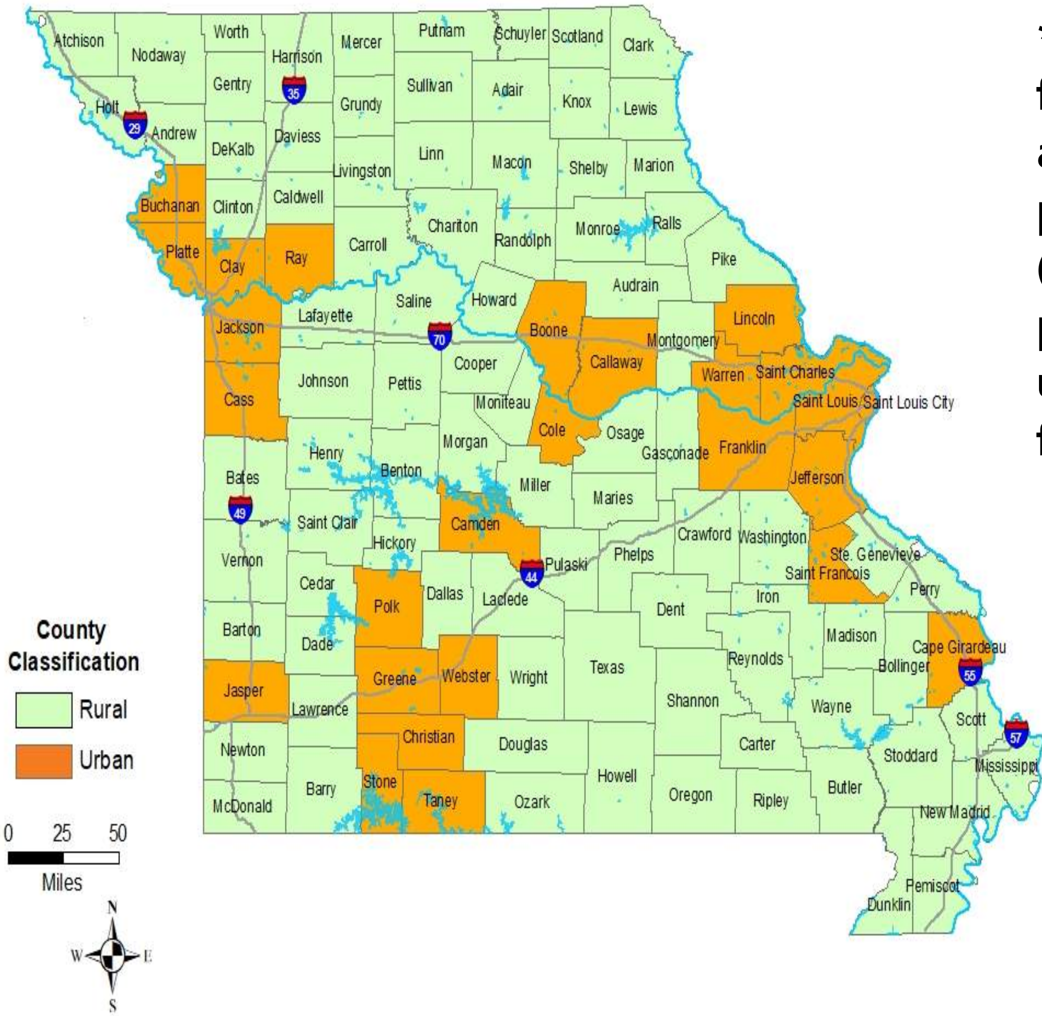
Missouri Planning Scenarios

for Drought-of-Record Conditions

Scenario	M&I Demands	Ag Demands	Climate	Supply Constraints	Overall Impact to Surface Water Supply and Demands		Percent Change from Baseline
					Category	Statewide (mgd)	Statewide (%)
Business-As-Usual	**Baseline M&I and Baseline Rural Demands**	**Med Ag Irr and Med Ag Processing**	**Historical T and P**	**Reservoir Sedimentation** *8.9% Reduction in Flow*	M&I Demands:	**52**	*no change from normal*
					Ag Demands:	**27**	
					Supply (streamflow):	**14,299**	
					Missouri River flow:	**16,320**	
					Category	Statewide (mgd)	Statewide (%)
Strong Economy/High Water Stress	**High M&I and Higher Rural Demands** *M&I Demands +25%* *Rural Demands +10%*	**High Ag Irr and Med-High Ag Processing**	**Hotter T and Lower P**	**Reservoir Sedimentation and Interstate Diversions out of Missouri River** *14% Reduction in Flow*	M&I Demands:	**68**	**31%**
					Ag Demands:	**81**	**200%**
					Supply (streamflow):	**12,804**	**10%**
					Missouri River flow:	**14,274**	**13%**
					Category	Statewide (mgd)	Statewide (%)
Substantial Agricultural Expansion	**Baseline M&I and Baseline Rural Demands**	**Med Ag Irr and Highest Ag Processing**	**Warmer T and Greater P**	**Reservoir Sedimentation and Interstate Diversions out of Missouri River** *14% Reduction in Flow*	M&I Demands:	**54**	**4%**
					Ag Demands:	**19**	**30%**
					Supply (streamflow):	**15,973**	**12%**
					Missouri River flow:	**14,274**	**13%**
					Category	Statewide (mgd)	Statewide (%)
Weak Economy/Low Water Stress	**Low M&I and Baseline Rural Demands** *M&I Demands -10%* *Rural Demands +10%*	**Med Ag Irr and Med Ag Processing**	**Warmer T and Greater P**	**Reservoir sedimentation** *8.9% Reduction in Flow*	M&I Demands:	**49**	**6%**
					Ag Demands:	**19**	**30%**
					Supply (streamflow):	**15,973**	**12%**
					Missouri River flow:	**16,320**	**0%**

Note: Limitations on Groundwater and Prolonged Supply Disruptions on River Intakes are also part of some scenarios

Urban/Rural County Classification

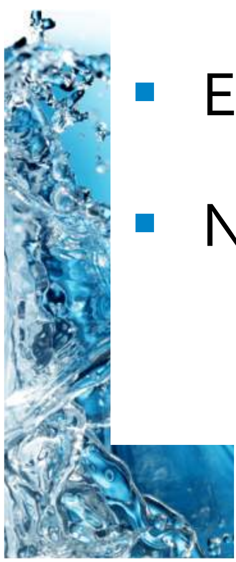


***Classification ONLY used for the purpose of assessing additional population growth (beyond the baseline population projections) used in the water demand forecast**

MISSOURI WATER RESOURCES PLAN

Business-As-Usual Scenario

- Baseline M&I demands
- Baseline rural demands
- Medium agriculture irrigation (baseline)
- Medium agriculture processing (baseline)
- Historical temperature and precipitation levels
- Existing water treatment levels
- No water supply constraints



MISSOURI WATER RESOURCES PLAN

Strong Economy / High Water Stress Scenario Methods and Assumptions

- Additional population growth by 2060:
  - +25% in urban counties
  - +10% in rural counties
- Applies to these sectors:
  - Major Water Systems (by major water system)
  - Self-supplied Residential and Minor Systems (at the county level)
  - Self-supplied Non-residential
  - Agriculture Irrigation
- Sources of water are assumed equal to 2016 proportions
- Hotter temperatures and lower rainfall trends

MISSOURI WATER RESOURCES PLAN

Weak Economy / Low Water Stress Scenario Methods and Assumptions

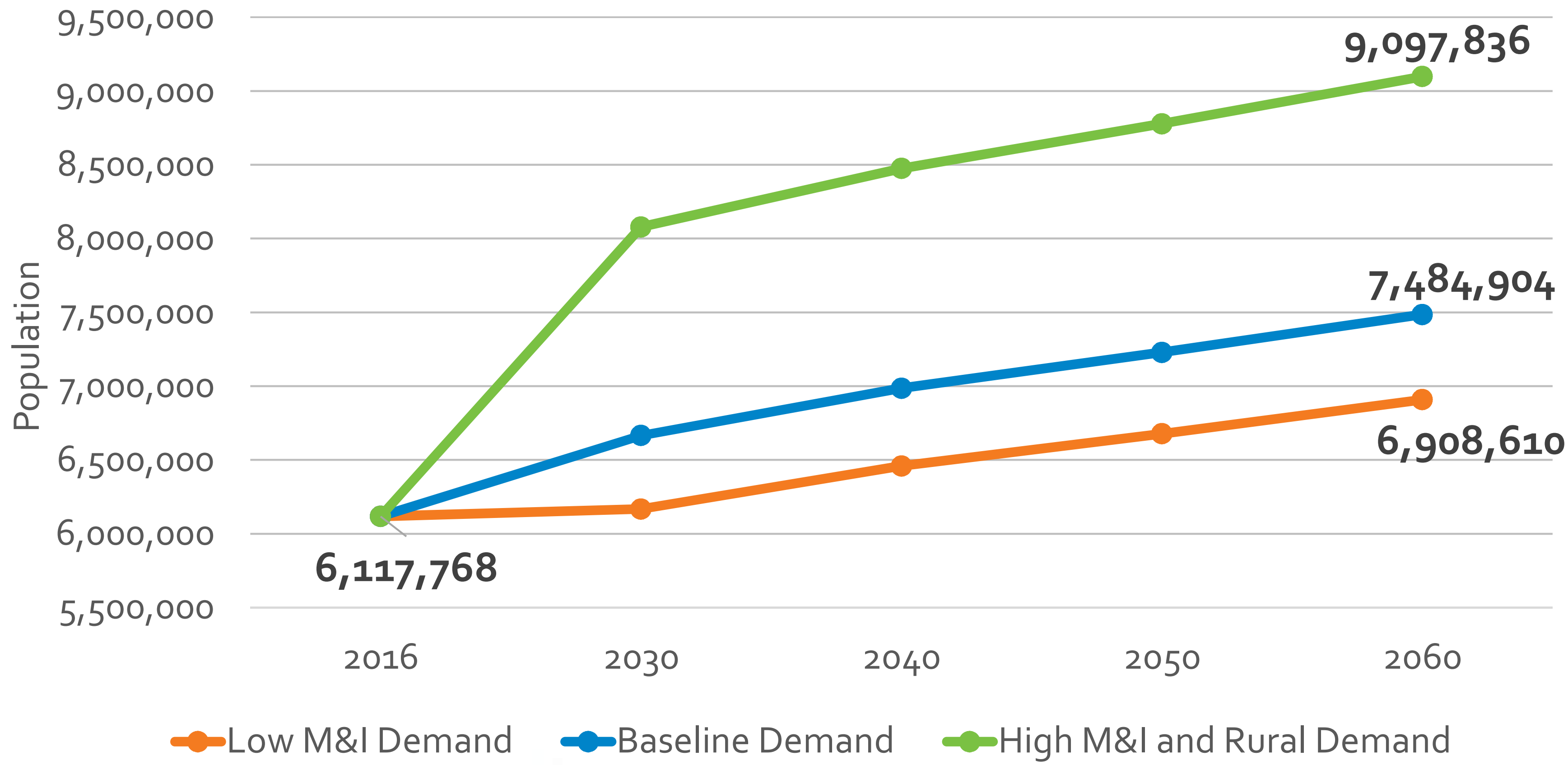
- Reduction in population growth by 2060:
  - -10% in urban counties
  - Baseline growth in rural counties
- Applies to these sectors:
  - Major Water Systems
- All other sector demands assumed at baseline
- Sources of water are assumed equal to 2016 proportions
- Warmer temperatures and more rainfall

MISSOURI WATER RESOURCES PLAN

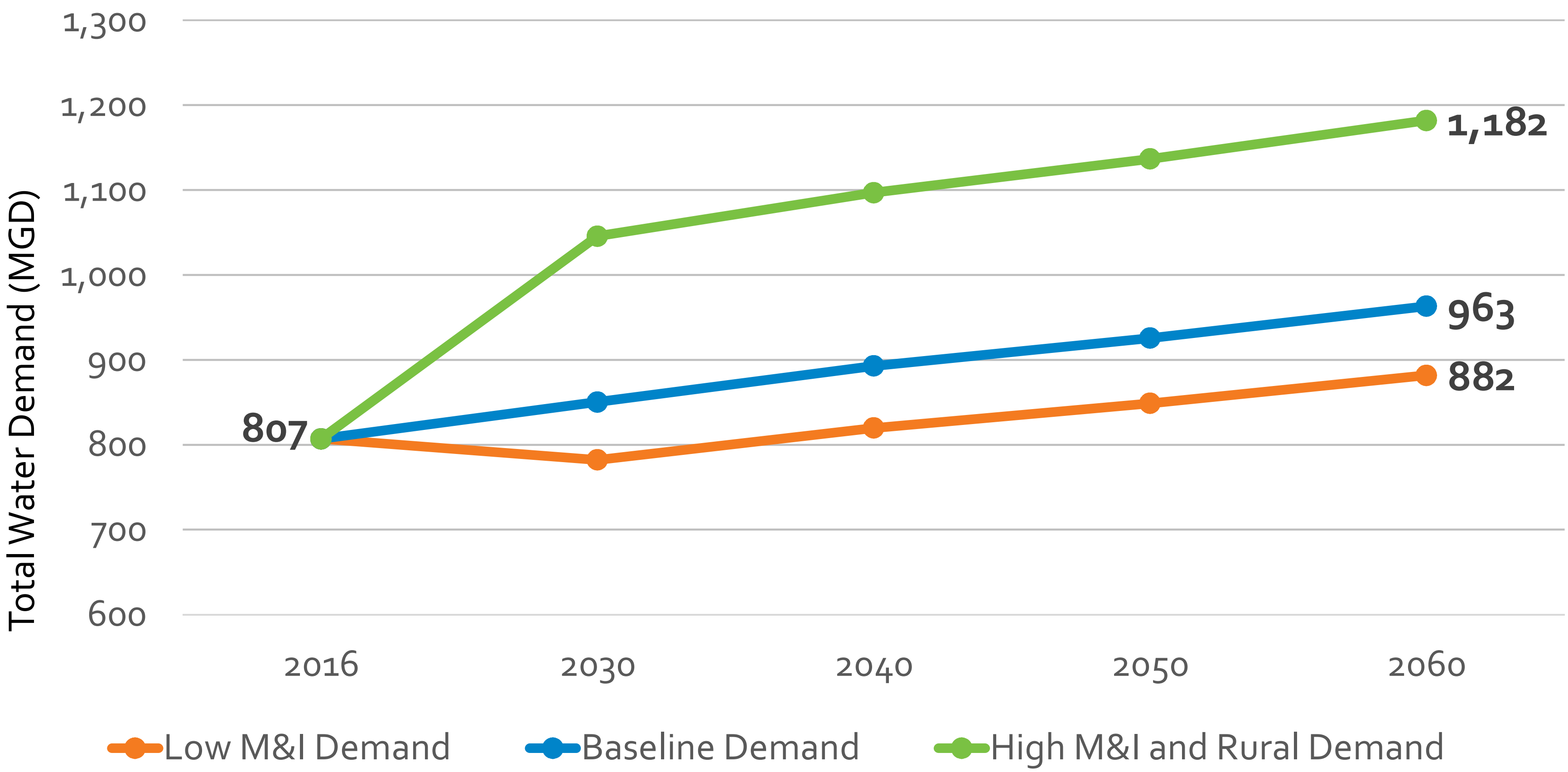
Substantial Agriculture Expansion Methods and Assumptions

- Applies to two sectors:
  - Self-supplied Nonresidential (by agriculture industry)
  - Agriculture Irrigation
- Baseline demands for all other sectors
- Sources of water are assumed equal to 2016 proportions

Population Projection Scenarios



Major Water Systems Demand by Scenario



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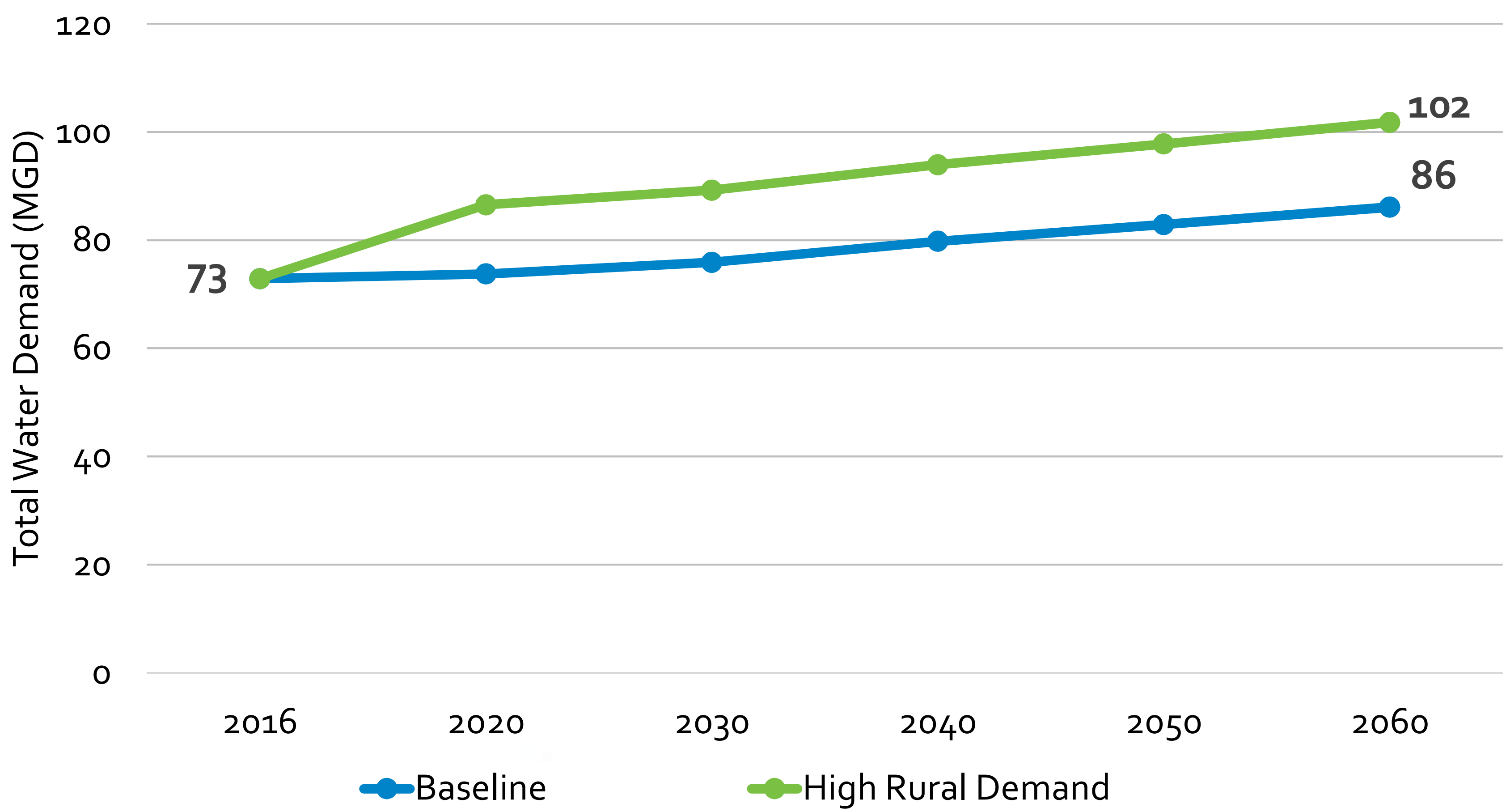
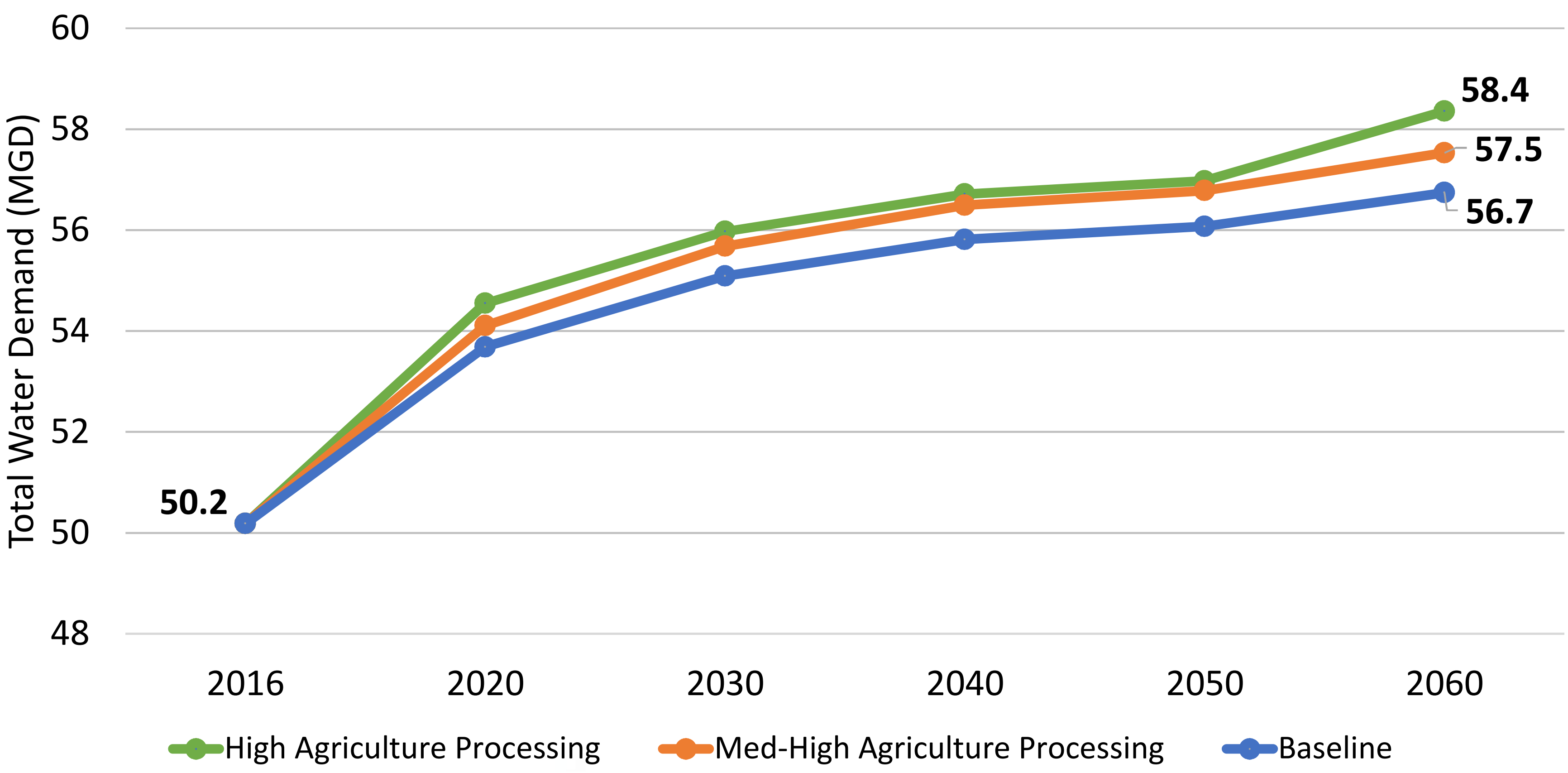
Self-Supplied Residential and Minor Systems



Note: Low Rural Demands were not calculated since they were not part of an scenario.

Self-Supplied Nonresidential



Note: It is unknown when new self supplied nonresidential facilities will be brought online therefore is assumed a percentage increase from baseline.

MISSOURI WATER RESOURCES PLAN

Climate Adjustment Factors for M&I Demands High Water Stress

- Developed using weather-demand regression model specific to MO and climate change model outputs
- Resulting adjustment factors by basin/HUC
- Multiplied by future projections to represent Hot and Dry weather

Basin	HUC4	Adjustment Factor for Hot & Dry Weather					
		May	June	July	Aug	Sept	Oct
Upper Mississippi-Salt	711	1.110	1.111	1.113	1.108	1.113	1.122
Upper Mississippi-Kaskaskia-Meramec	714	1.089	1.108	1.113	1.111	1.111	1.111
Lower Mississippi-St. Francis	802	1.089	1.107	1.113	1.113	1.110	1.108
Missouri-Nishnabotna	1024	1.093	1.112	1.119	1.115	1.117	1.122
Chariton-Grand	1028	1.091	1.112	1.117	1.112	1.115	1.123
Gasconade-Osage	1029	1.087	1.109	1.111	1.106	1.111	1.118
Lower Missouri	1030	1.088	1.110	1.112	1.107	1.112	1.120
Upper White	1101	1.087	1.105	1.111	1.111	1.108	1.106
Neosho-Verdigris	1107	1.086	1.107	1.110	1.104	1.108	1.114

MISSOURI WATER RESOURCES PLAN

Climate Adjustment Factors – Low Water Stress

- Developed using weather-demand regression model specific to MO and climate change model outputs
- Resulting adjustment factors by basin/HUC
- Multiplied by future projections to represent Warm and Wet weather

Basin	HUC4	Adjustment Factor for Warm & Wet Weather					
		May	June	July	Aug	Sept	Oct
Upper Mississippi-Salt	711	1.039	1.040	1.044	1.053	1.064	1.062
Upper Mississippi-Kaskaskia-Meramec	714	1.051	1.044	1.045	1.049	1.059	1.068
Lower Mississippi-St. Francis	802	1.057	1.052	1.052	1.056	1.064	1.070
Missouri-Nishnabotna	1024	1.037	1.051	1.058	1.064	1.068	1.062
Chariton-Grand	1028	1.043	1.052	1.056	1.062	1.067	1.065
Gasconade-Osage	1029	1.045	1.052	1.057	1.059	1.067	1.066
Lower Missouri	1030	1.046	1.053	1.058	1.060	1.068	1.067
Upper White	1101	1.056	1.052	1.051	1.055	1.063	1.068
Neosho-Verdigris	1107	1.044	1.052	1.057	1.058	1.066	1.064

Climate / Hydrologic Variability

Climate Variability – Hydrology Projections

- Overall Approach
  - 2060 planning horizon (± 15 years) to align with demand projections
  - Three spatial grid cells to represent statewide General Circulation model (GCM) projections: NW corner, Central and SE corner
  - Use published "gridded runoff" data set to adjust observed stream flows within Hybrid Delta Ensemble (HDe) methodology
  - 9 HUC4 basins x 2 climate projection ensembles (groups) = 18 new hydrologic traces

MISSOURI WATER RESOURCES PLAN

Climate Variability – Hydrology Projections

- Spatial representation:
  - 3 General Circulation Model (GCM) grid cells
  - Capturing regional differences in climate projections

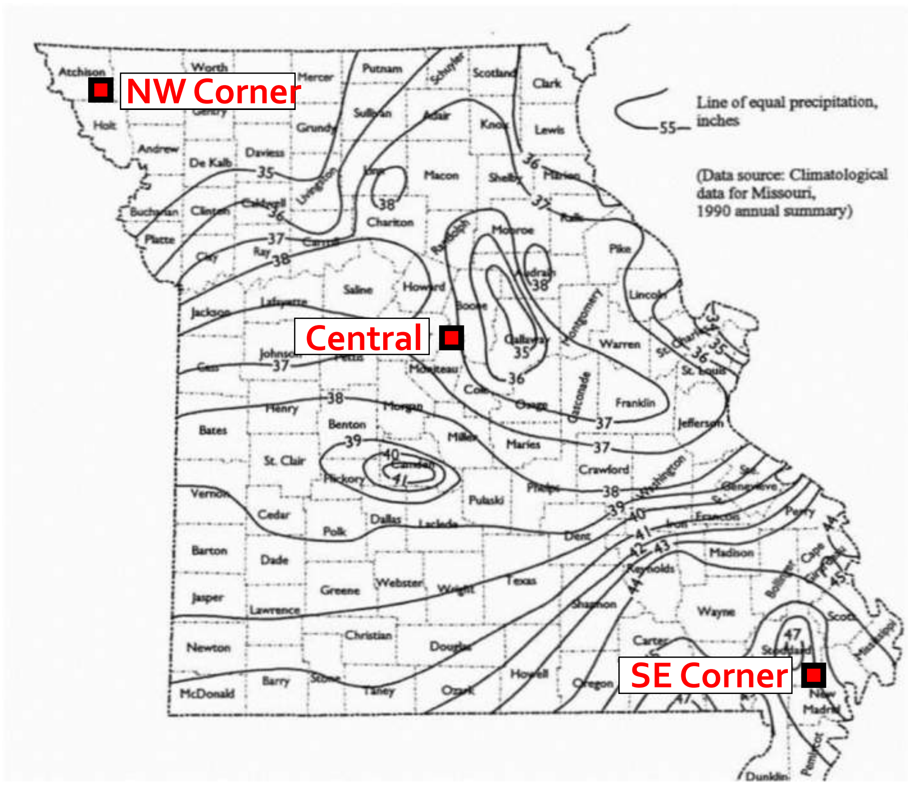
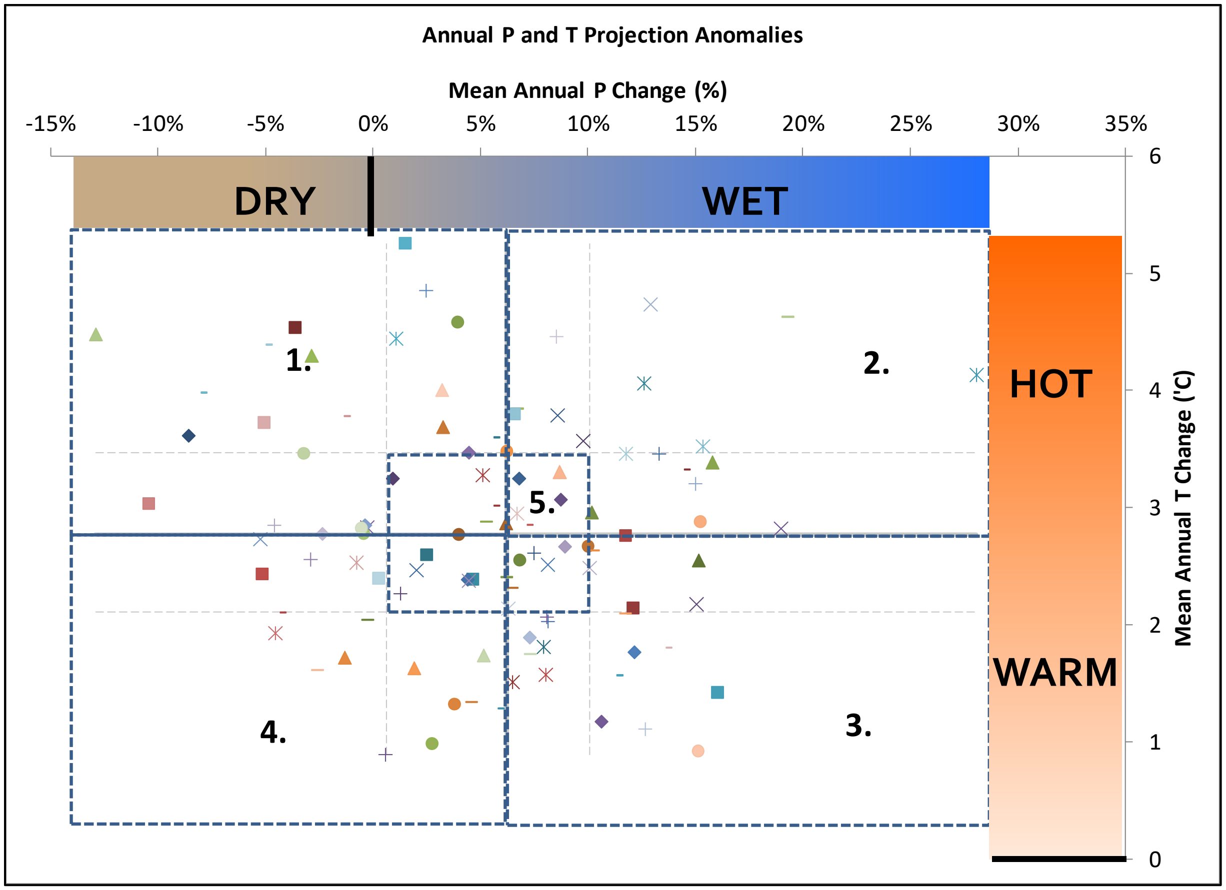


Image of precipitation contours from Surface Water Resources of Missouri, MoDNR, 1995

MISSOURI WATER RESOURCES PLAN

Climate Variability – Hydrology Projections

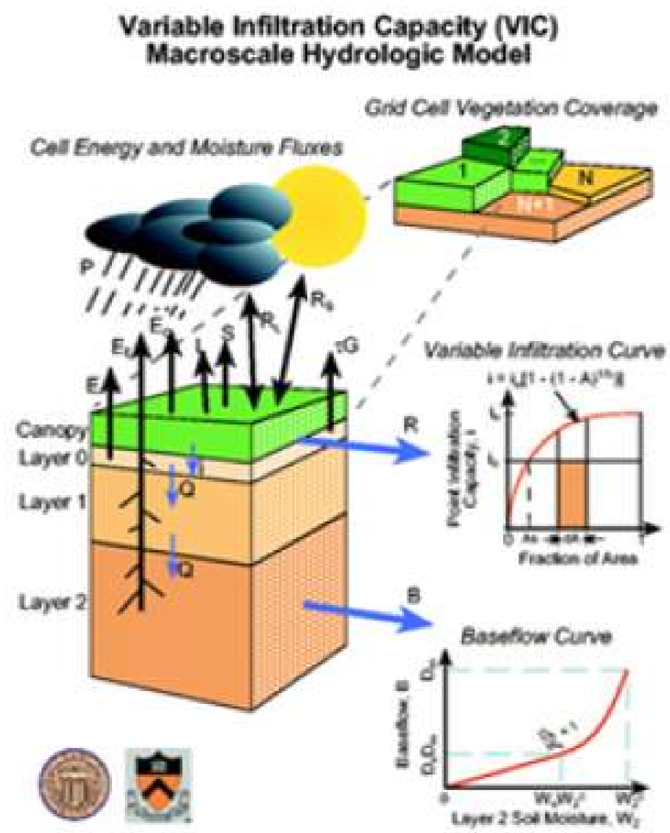
- Ensembling (grouping): HOT/DRY (1) and WARM/WET (3) Selected for Scenarios



MISSOURI WATER RESOURCES PLAN

Climate Variability – Hydrology Projections

- Gridded runoff:
  - Each GCM projection (precipitation and temperature) used as input to macroscale hydrologic model (VIC)
  - Applied for same 1/8th degree grid
  - Spatially distributed; coarsely calibrated at large basin scale
  - Output = monthly runoff (mm) projections for each grid cell; 2000 - 2099



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Climate Variability – Hydrology Projections

- Hybrid Delta Ensemble (HDe) method:
  - Delta = modeled future – modeled past (bias)
  - Ensemble (Group) = multiple GCM projections combined (uncertainty)
  - Hybrid = range (percentiles) of delta values for each month

Climate Variability – Demand Projections

- Overall Approach
  - 2060 planning horizon (± 15 years) to align with demand projections
  - Three spatial grid cells to represent statewide GCM projections: NW corner, central, SE corner
  - Use difference in temperature and ratio of precipitation to adjust demands

Climate Variability – Demand Projections

- Example Results

Hot/Dry

	Avg. Temperature Change Term ('C)	Avg. Precipitation Change Factor
Jan	3.57	1.08
Feb	3.21	1.13
Mar	3.15	1.12
Apr	2.92	1.16
May	3.25	1.02
Jun	3.86	0.89
Jul	4.18	0.85
Aug	4.25	0.90
Sep	4.18	0.94
Oct	3.91	0.96
Nov	3.24	1.00
Dec	3.80	1.05

Warm/Wet

	Avg. Temperature Change Term ('C)	Avg. Precipitation Change Factor
Jan	2.16	1.07
Feb	1.89	1.18
Mar	1.79	1.18
Apr	1.79	1.16
May	1.80	1.15
Jun	1.91	1.11
Jul	2.07	1.07
Aug	2.30	1.01
Sep	2.47	1.02
Oct	2.20	1.06
Nov	1.90	1.14
Dec	2.14	1.08

Drought Conditions Streamflow

HUC 4	Drought-of-Record Year(s) Used	Percent Difference from Average Year Streamflow
Upper Mississippi-Salt	1954 & 1956	82%
Upper Mississippi- Kaskaskia-Meramec	1954	15%
Lower Mississippi-St. Francis	1954	57%
Missouri-Nishnabotna	1956	42%
Chariton-Grand	1956	81%
Gasconade-Osage	1954	68%
Lower Missouri	1956	95%
Upper White	1954	48%
Neosho-Verdigris	1954 & 1956	87%

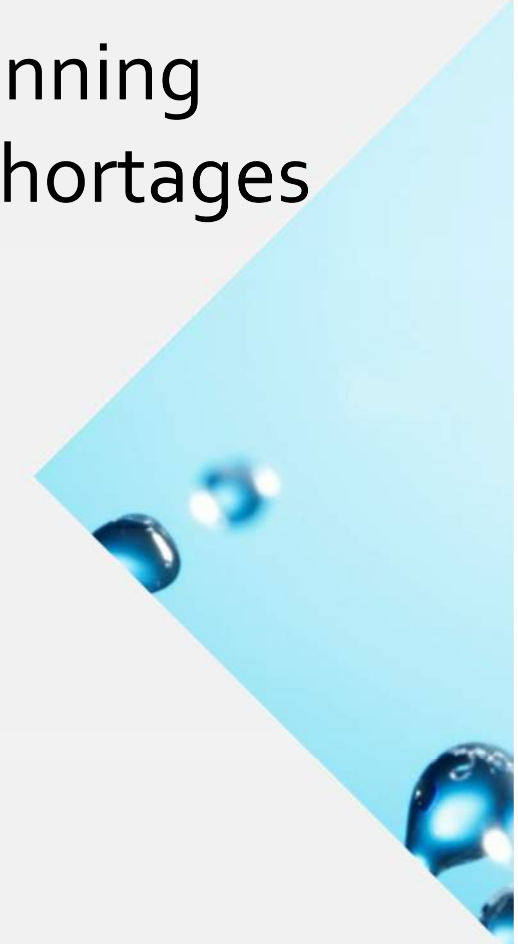
MISSOURI WATER RESOURCES PLAN

Climate Scenarios - Streamflow Adjustments

HUC4	Drought-of-Record Streamflow	Hot/Dry Scenario Streamflow	Warm/Wet Scenario Streamflow
Upper Mississippi-Salt	562	436	588
Upper Mississippi- Kaskaskia-Meramec	3,614	3,225	4,199
Lower Mississippi-St. Francis	710	657	685
Missouri-Nishnabotna	893	857	1,114
Chariton-Grand	702	550	779
Gasconade-Osage	2,834	2,532	3,143
Lower Missouri	314	241	356
Upper White	4,407	4,082	4,809
Neosho-Verdigris	262	223	301

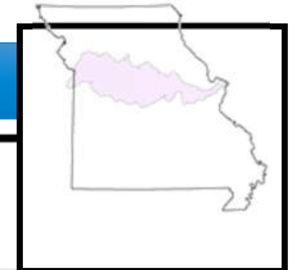
Flows in mgd. *Flows represent streamflow generated within each HUC4 and do not include flow from the Missouri or Mississippi rivers coming from out-of-state.*

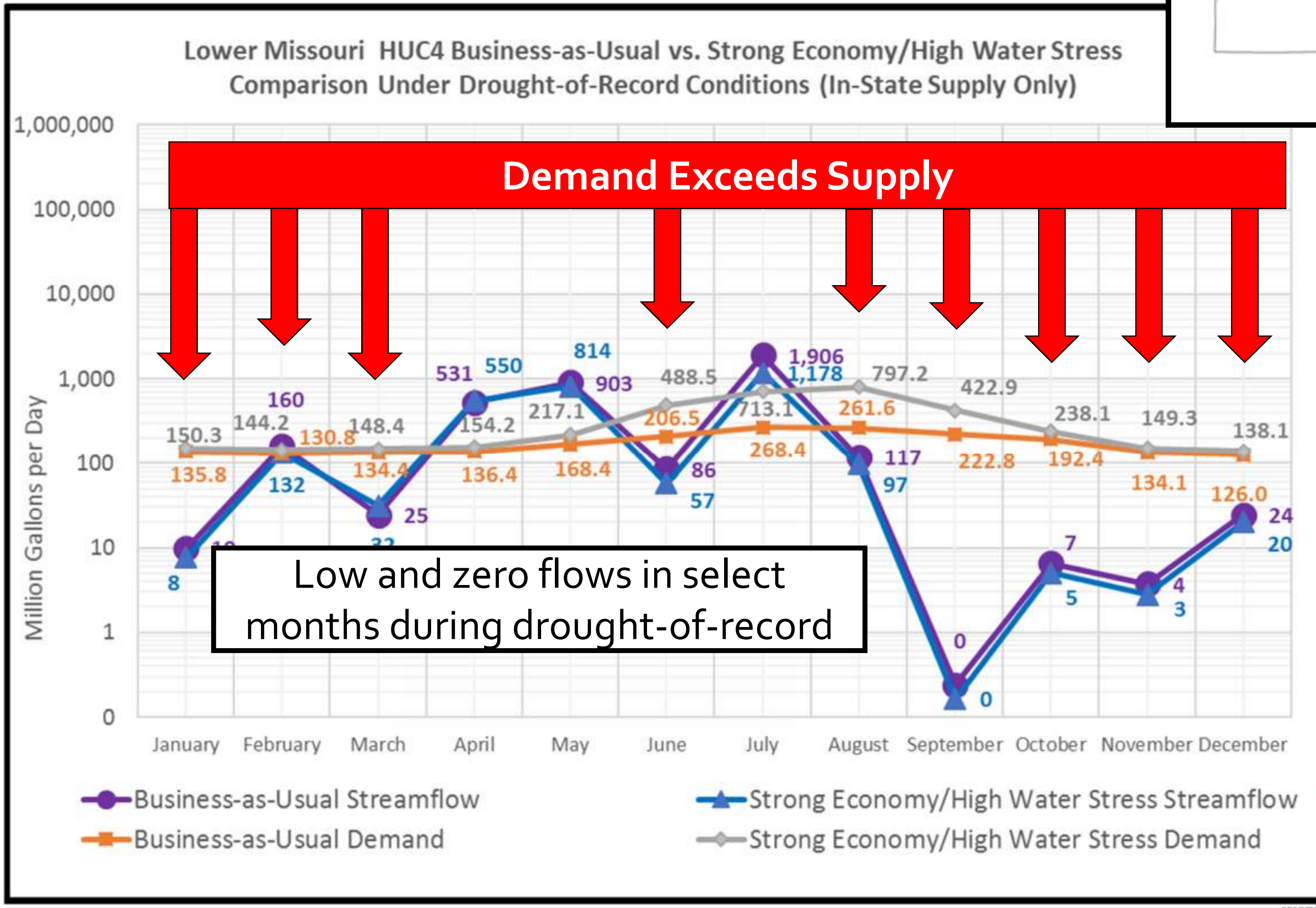
Scenario Planning
Water Supply Shortages



Scenario Results - Surface Water Supply
Business-as-Usual vs. Strong Economy/High Water Stress
Lower Missouri HUC4

In-State generated flows only. Excludes demands on Missouri River

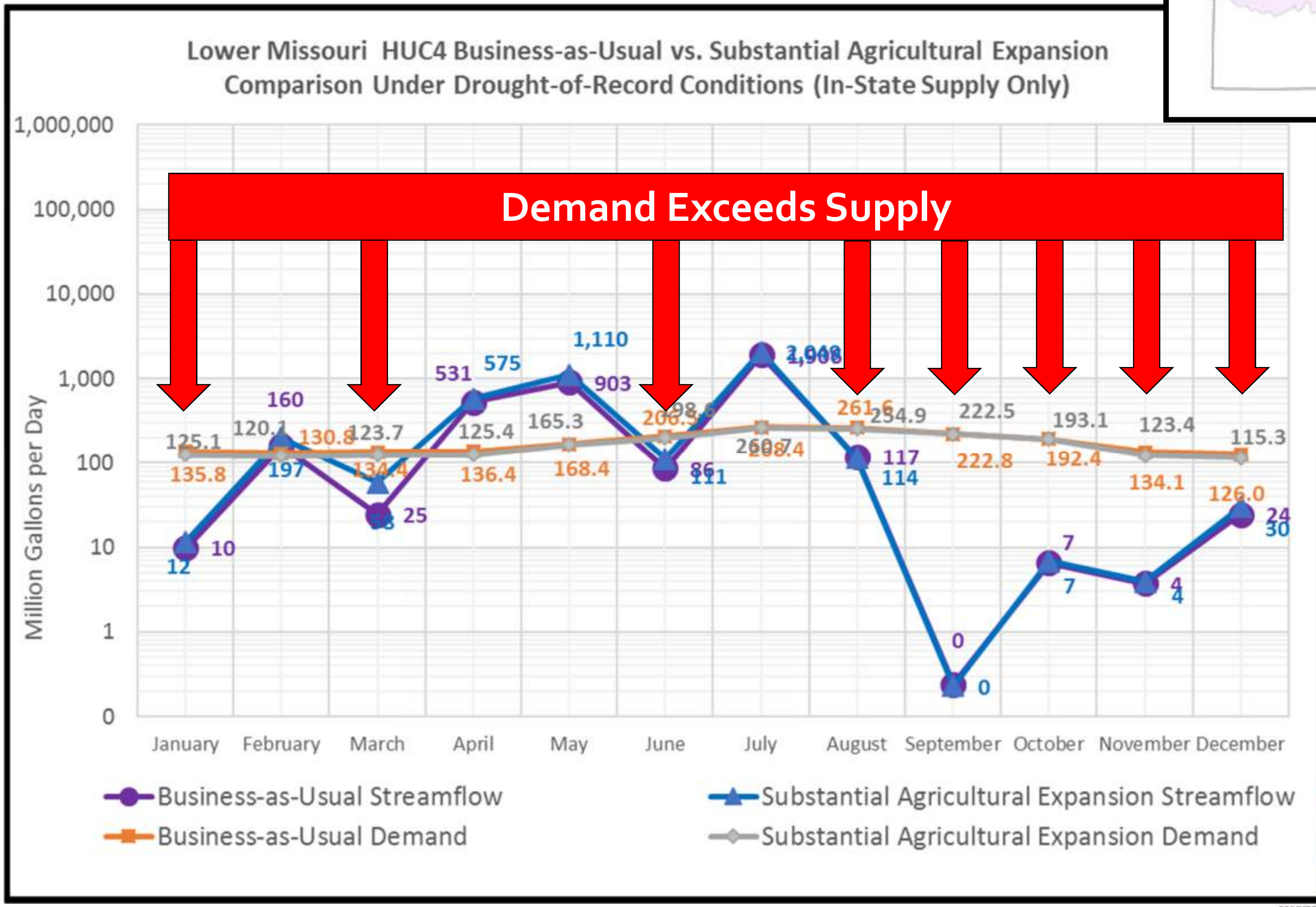




WATER RESOURCES PLAN

Scenario Results - Surface Water Supply
Business-as-Usual vs. Substantial Agricultural Expansion
Lower Missouri HUC4

In-State generated flows only. Excludes demands on Missouri River



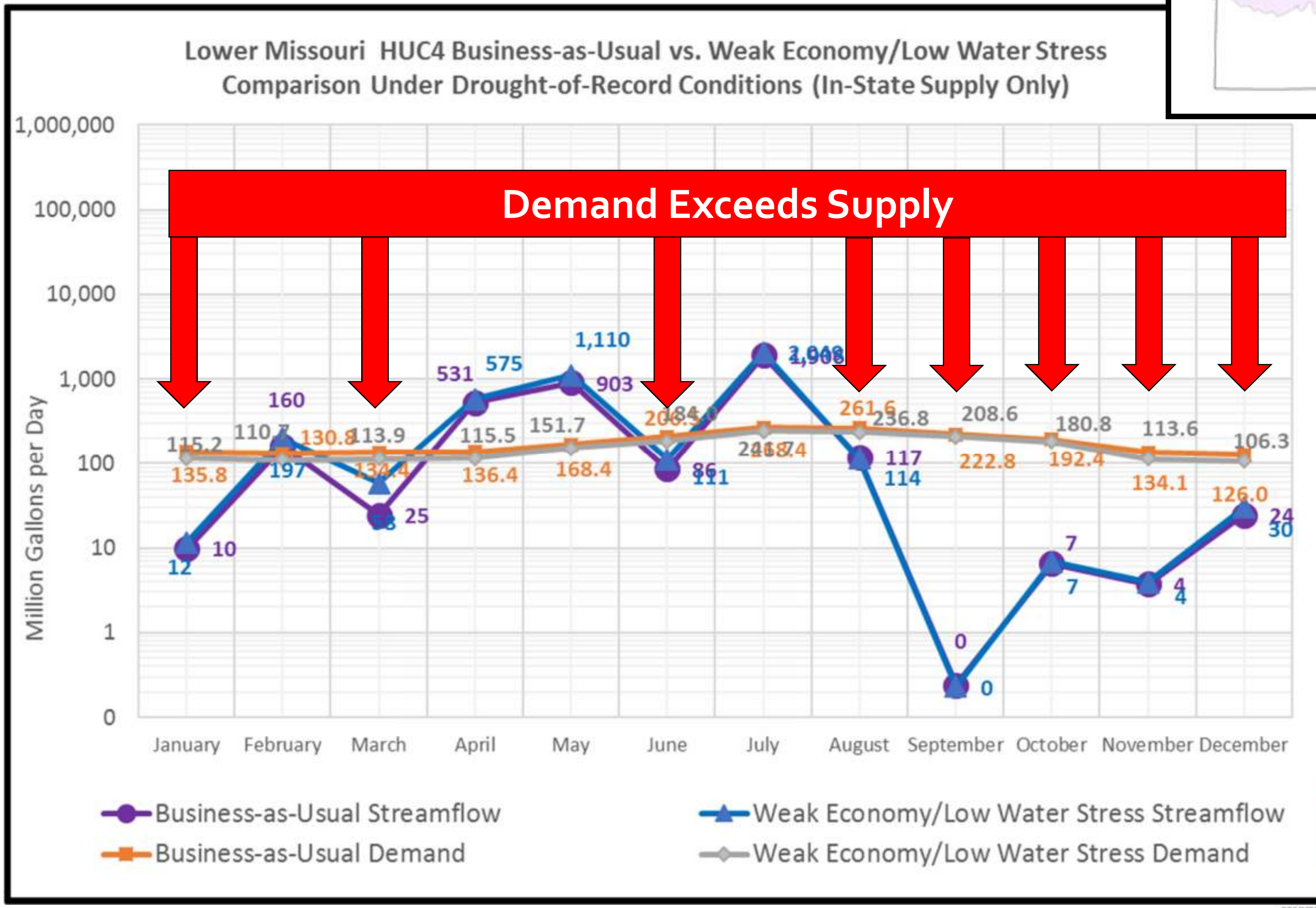
WATER RESOURCES PLAN

Scenario Results - Surface Water Supply

Business-as-Usual vs. Weak Economy/Low Water Stress

Lower Missouri HUC4

In-State generated flows only. Excludes demands on Missouri River



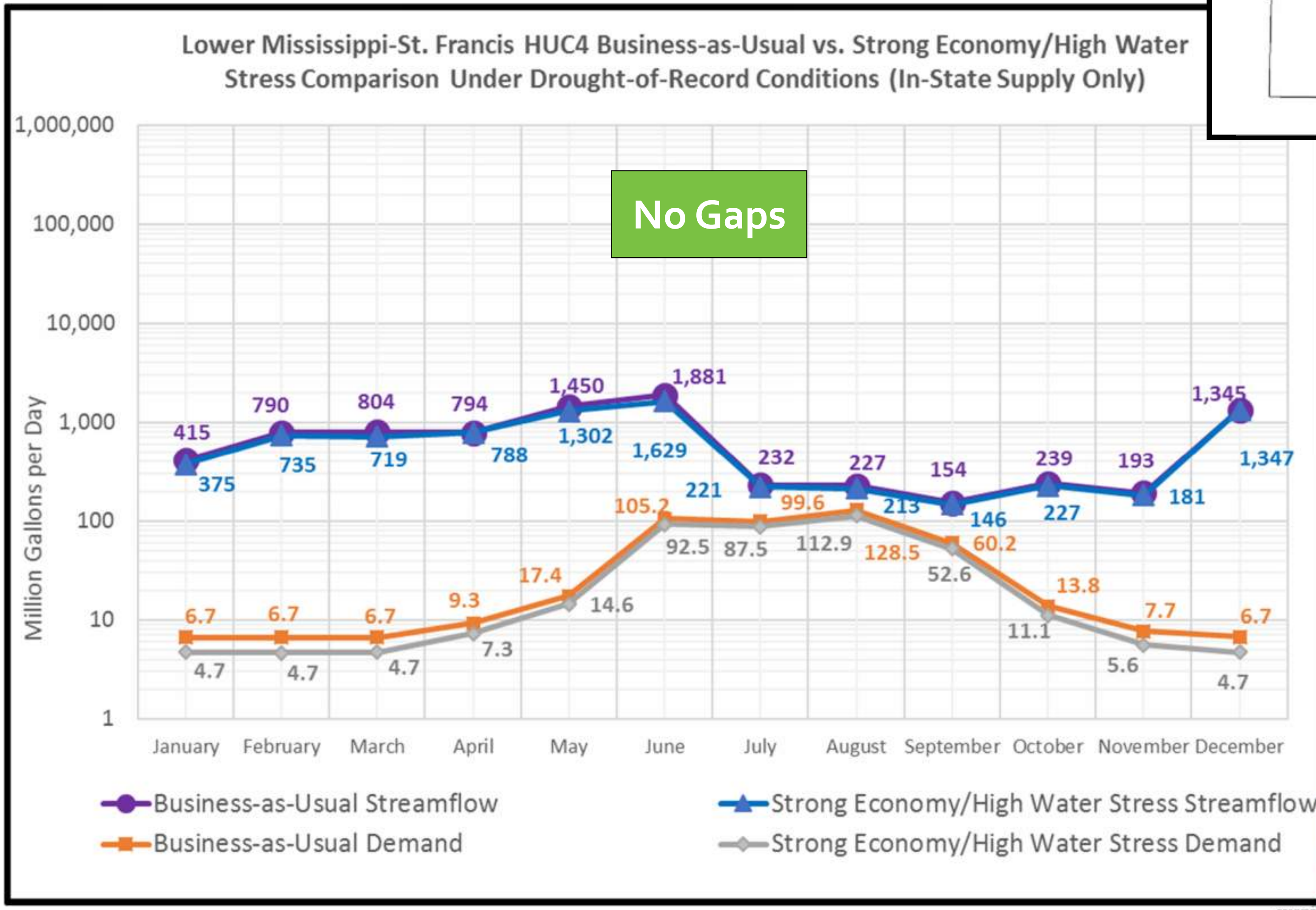
WATER RESOURCES PLAN

Scenario Results - Surface Water Supply

Business-as-Usual vs. Strong Economy/High Water Stress

Lower Mississippi-St. Francis HUC4

In-State generated flows only. Excludes demands on Mississippi River



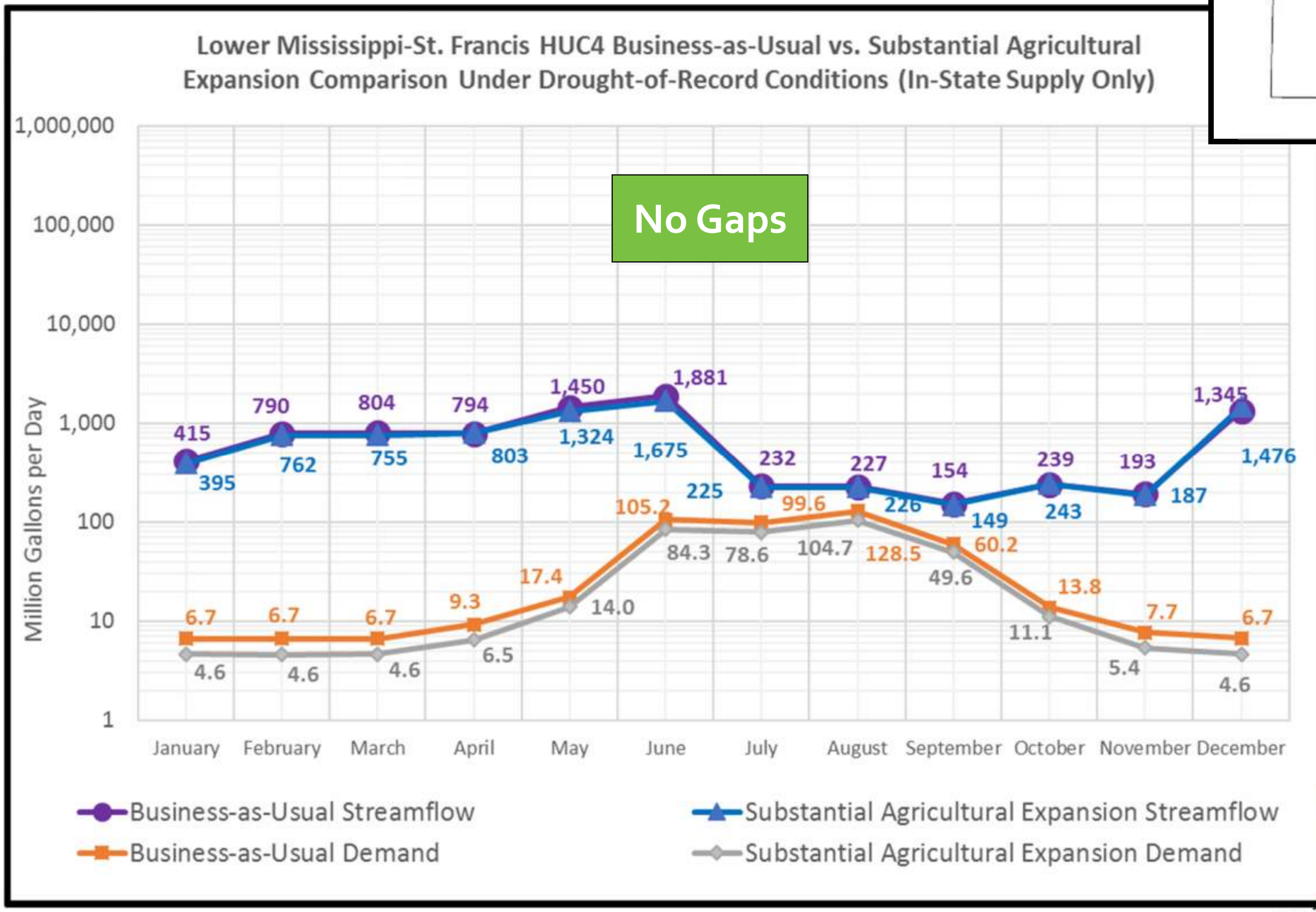
MISSOURI WATER RESOURCES PLAN

Scenario Results - Surface Water Supply

Business-as-Usual vs. Substantial Agricultural Expansion

Lower Mississippi-St. Francis HUC4

In-State generated flows only. Excludes demands on Mississippi River



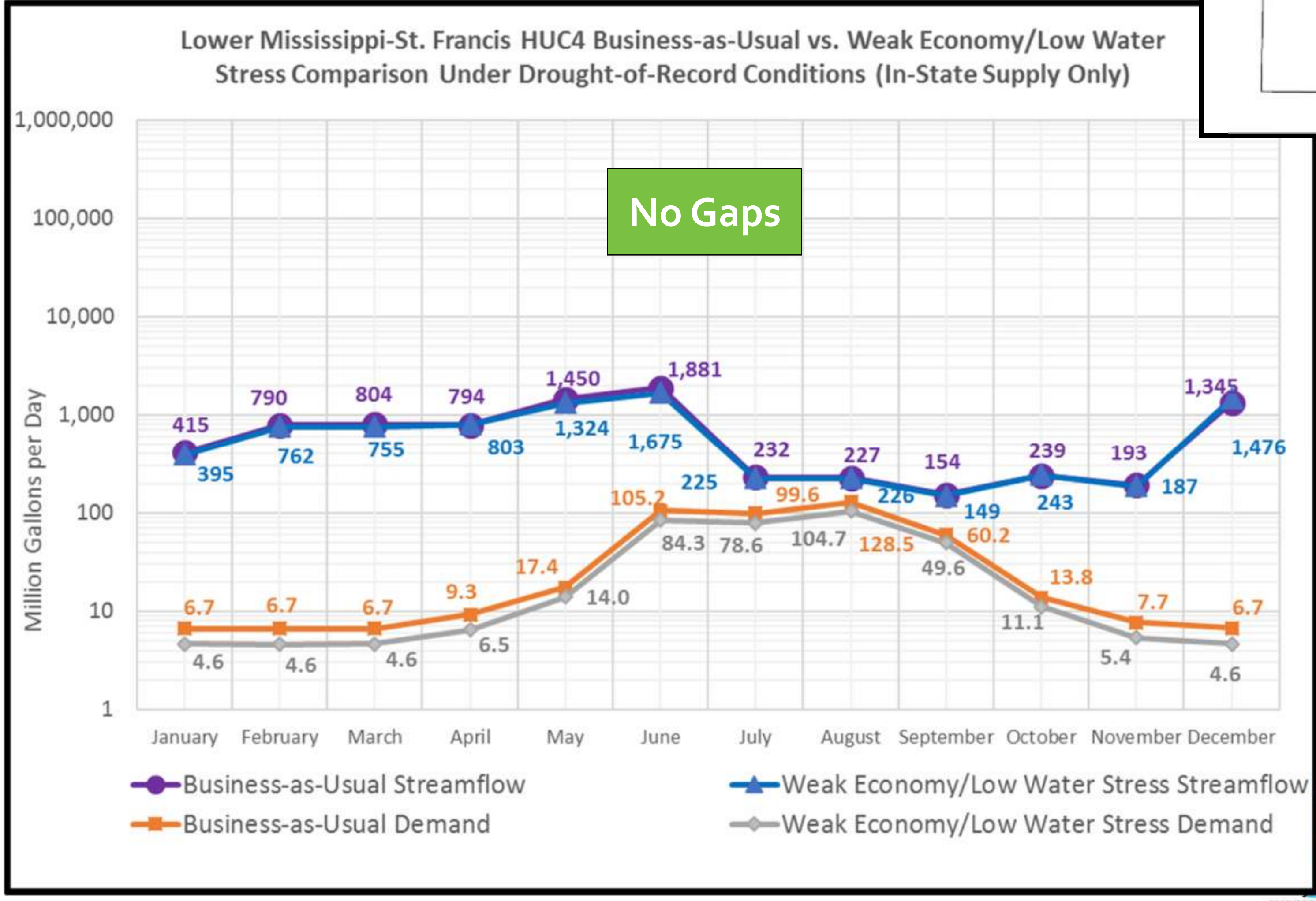
WATER RESOURCES PLAN

Scenario Results - Surface Water Supply

Business-as-Usual vs. Weak Economy/Low Water Stress

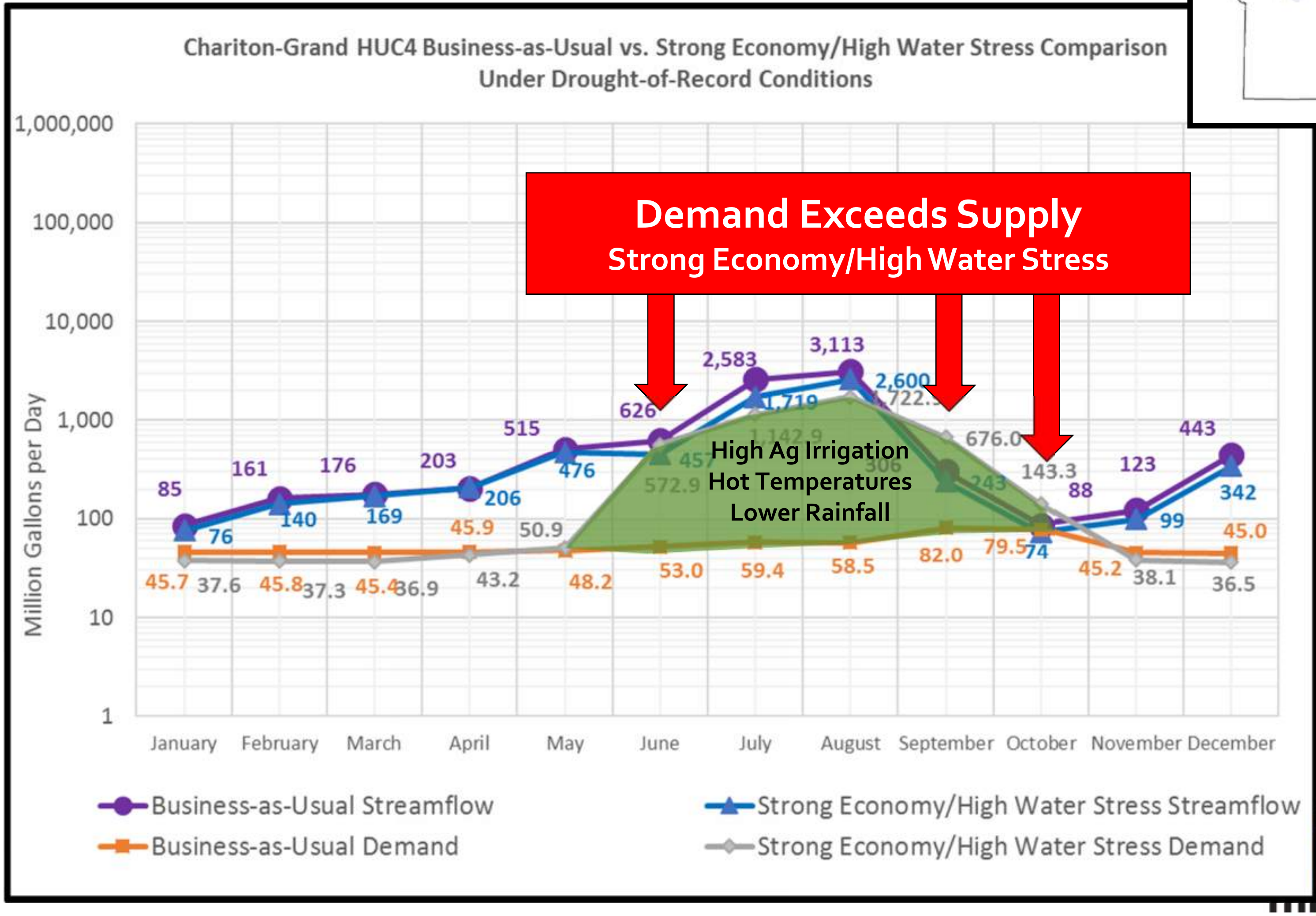
Lower Mississippi-St. Francis HUC4

In-State generated flows only. Excludes demands on Mississippi River



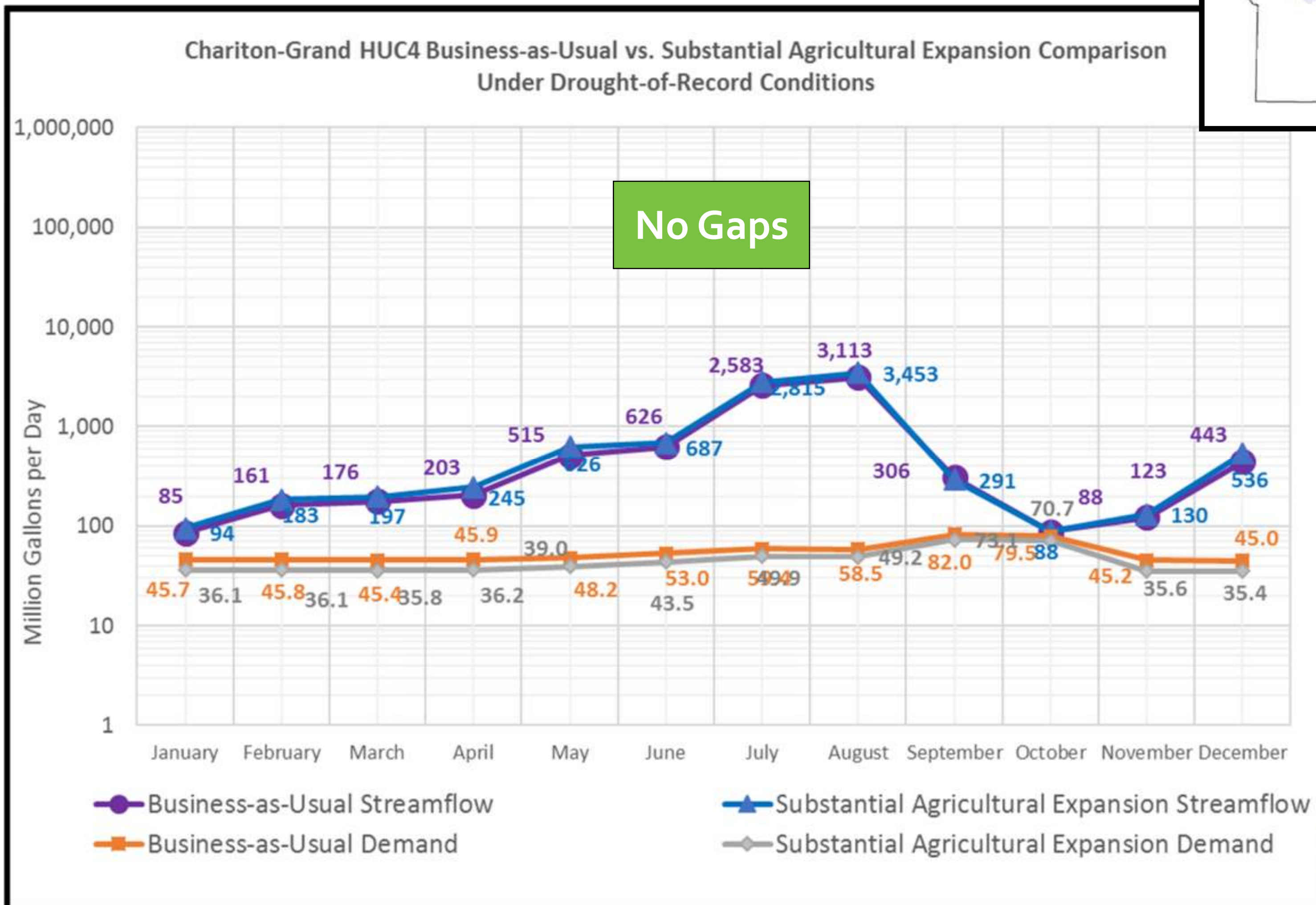
MISSOURI WATER RESOURCES PLAN

Scenario Results - Surface Water Supply
Business-as-Usual vs. Strong Economy/High Water Stress
Chariton Grand HUC4



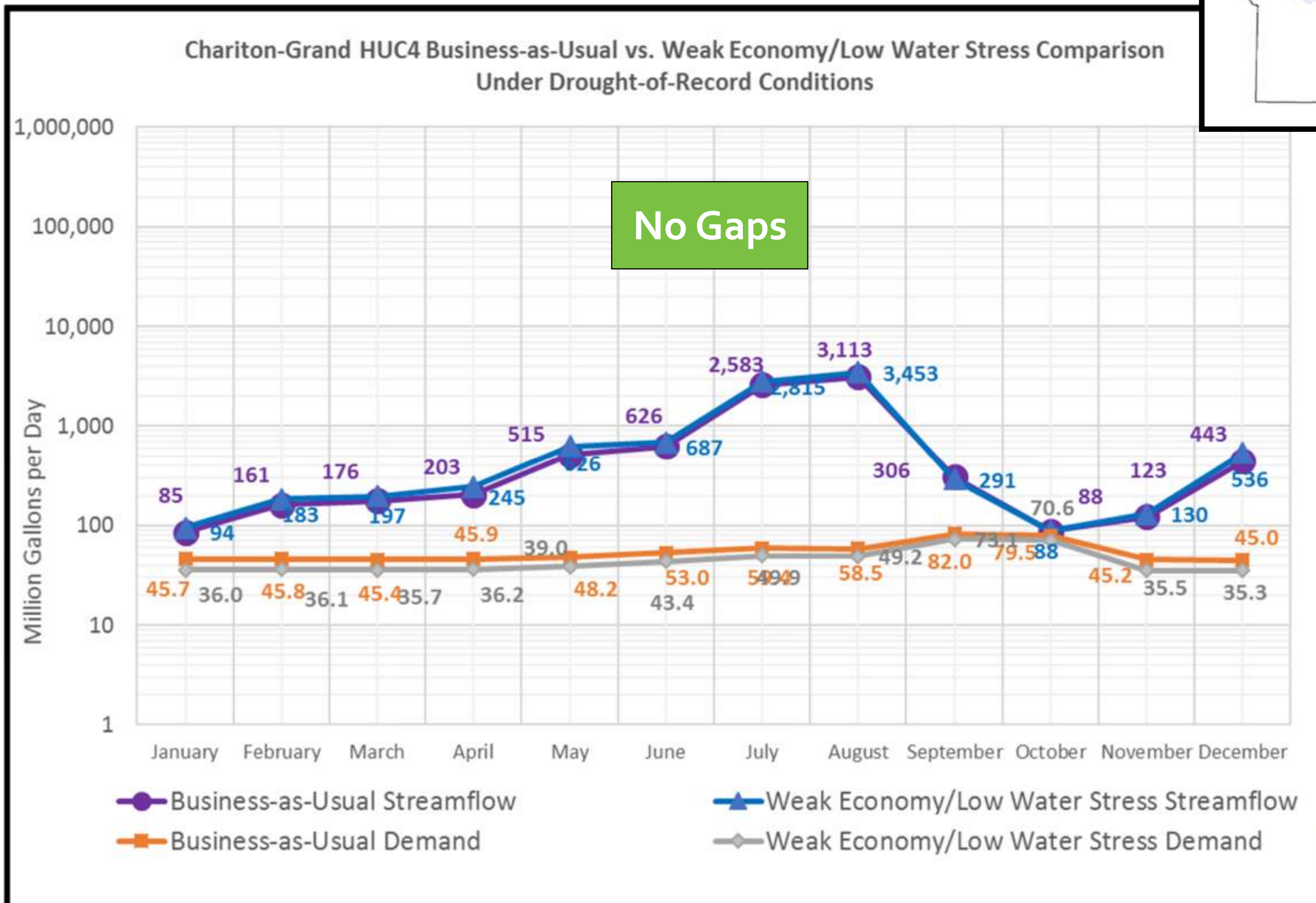
WATER RESOURCES PLAN

Scenario Results - Surface Water Supply
Business-as-Usual vs. Substantial Agricultural Expansion
Chariton Grand HUC4



WATER RESOURCES PLAN

Scenario Results - Surface Water Supply
Business-as-Usual vs. Weak Economy/Low Water Stress
Chariton Grand HUC4



WATER RESOURCES PLAN

Business-As-Usual Scenario

Drought-of-Record Conditions
Surface Water Generated In-Basin

In-State generated flows only. Excludes demands on Missouri and Mississippi rivers

Surface Water Generated In HUC4/HUC8
Scenario: **Business-as-Usual**
Condition: **Drought-of-Record**

No Gap
Basin Demand within 20% of Supply
Demand Exceeds Supply

HUC4	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
711	Upper Mississippi-Salt												
714	Upper Mississippi-Kaskaskia-Meramec												
802	Lower Mississippi-St. Francis												
1024	Missouri-Nishnabotna												
1028	Chariton-Grand												
1029	Gasconade-Osage												
1030	Lower Missouri												
1101	Upper White												
1107	Neosho-Verdigris												

HUC8	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10280101	Upper Grand												
10280102	Thompson												
10280103	Lower Grand												
10280201	Upper Chariton												
10280202	Lower Chariton												
10280203	Little Chariton												
10290103	Little Osage												

Business-As-Usual Scenario

Drought-of-Record Conditions
Surface Water Generated In-Basin

In-State generated flows only. Excludes demands on Missouri and Mississippi rivers

Surface Water Generated In HUC4/HUC8
Scenario: **Business-as-Usual**
Condition: **Drought-of-Record**

No Gap
Basin Demand within 20% of Supply
Demand Exceeds Supply

HUC4	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
711	Upper Mississippi-Salt												
714	Upper Mississippi-Kaskaskia-Meramec												
802	Lower Mississippi-S												
1024	Missouri-Nishnabot												
1028	Chariton-Grand												
1029	Gasconade-Osage												
1030	Lower Missouri												
1101	Upper White												
1107	Neosho-Verdigris												

Gage used had low or zero flow in select months during drought-of-record.

HUC8	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10280101	Upper Grand												
10280102	Thompson												
10280103	Lower Grand												
10280201	Upper Chariton												
10280202	Lower Chariton												
10280203	Little Chariton												
10290103	Little Osage												

Strong-Economy/High Water Stress Scenario

Drought-of-Record Conditions

Surface Water Generated In-Basin

Surface Water Generated In HUC4/HUC8

Scenario: **Strong-Economy/High Water Stress**

Condition: **Drought-of-Record**

No Gap

Basin Demand within 20% of Supply

Demand Exceeds Supply

In-State generated flows only. Excludes demands on Missouri and Mississippi rivers

HUC4	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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1024	Missouri-Nishnabotna												
1028	Chariton-Grand												
1029	Gasconade-Osage												
1030	Lower Missouri												
1101	Upper White												
1107	Neosho-Verdigris												

HUC8	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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10280103	Lower Grand												
10280201	Upper Chariton												
10280202	Lower Chariton												
10280203	Little Chariton												
10290103	Little Osage												

Substantial Agricultural Expansion

Drought-of-Record Conditions
Surface Water Generated In-Basin

In-State generated flows only. Excludes demands on Missouri and Mississippi rivers

Surface Water Generated In HUC4/HUC8
Scenario: **Substantial Agricultural Expansion**
Condition: **Drought-of-Record**

No Gap
Basin Demand within 20% of Supply
Demand Exceeds Supply

HUC4	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
711	Upper Mississippi-Salt												
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10280202	Lower Chariton												
10280203	Little Chariton												
10290103	Little Osage												

Weak Economy/Low Water Stress

Drought-of-Record Conditions

Surface Water Generated In-Basin

In-State generated flows only. Excludes demands on Missouri and Mississippi rivers

Surface Water Generated In HUC4/HUC8

Scenario: **Week Economy/Low Water Stress**

Condition: **Drought-of-Record**

No Gap

Basin Demand within 20% of Supply

Demand Exceeds Supply

HUC4	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
711	Upper Mississippi-Salt												
714	Upper Mississippi-Kaskaskia-Meramec												
802	Lower Mississippi-St. Francis												
1024	Missouri-Nishnabotna												
1028	Chariton-Grand												
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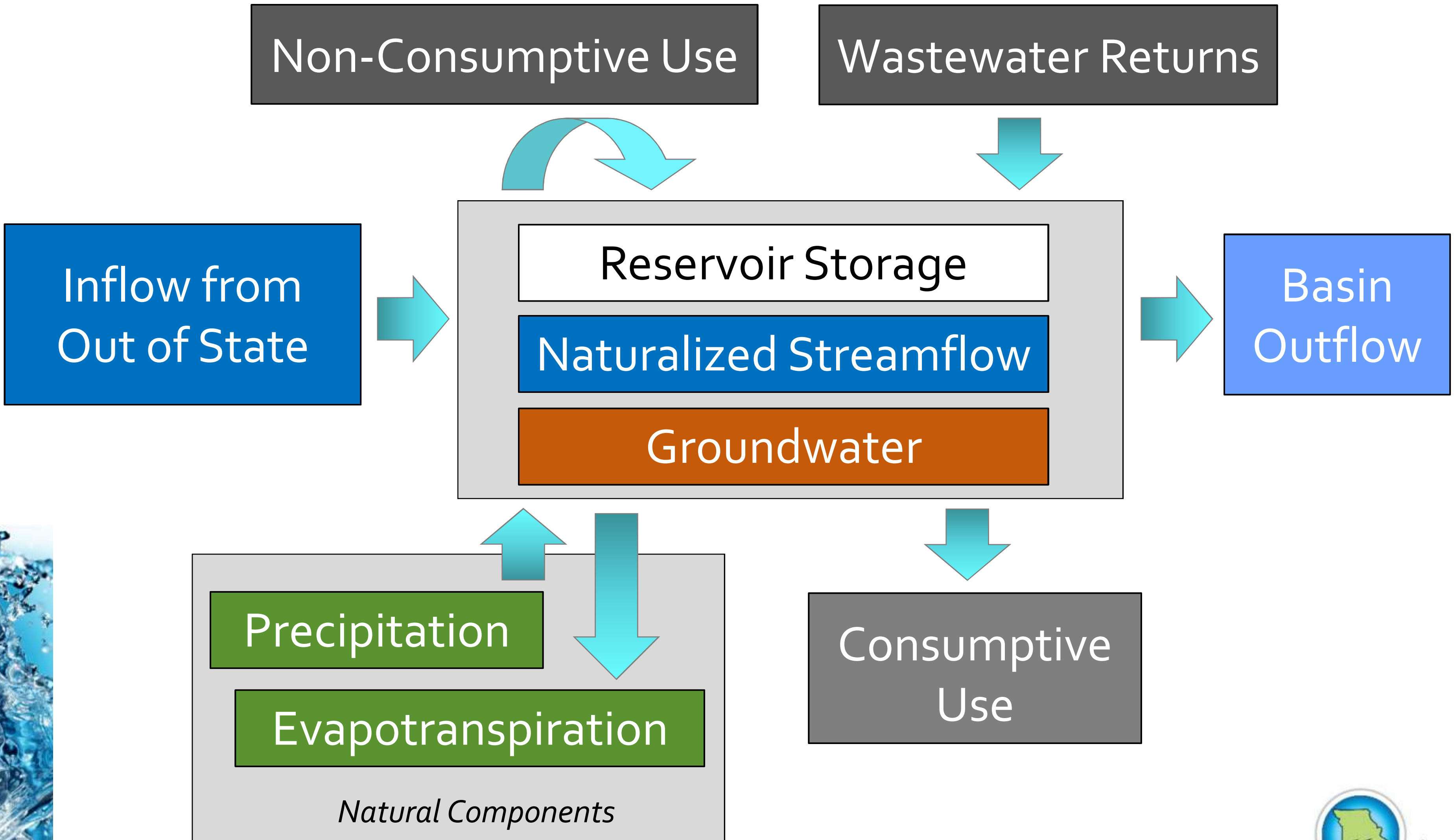
HUC8	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10280101	Upper Grand												
10280102	Thompson												
10280103	Lower Grand												
10280201	Upper Chariton												
10280202	Lower Chariton												
10280203	Little Chariton												
10290103	Little Osage												

Short Break

Groundwater Budget Update

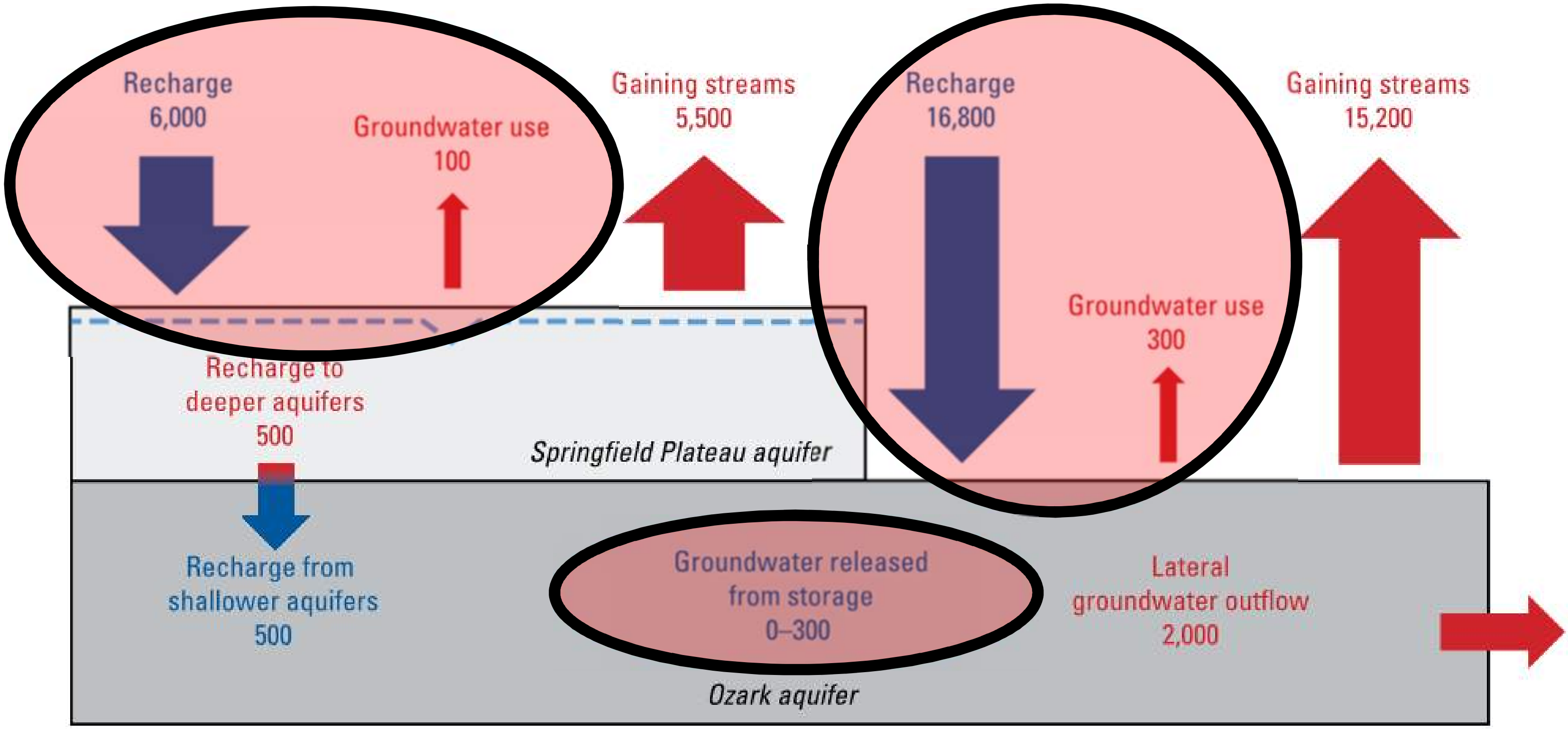
Total Water Budget



Groundwater Budgets

For State Water Plan, Budgets focus on Recharge, Withdrawals and Storage

Ozark Aquifer System, Current Day Budget



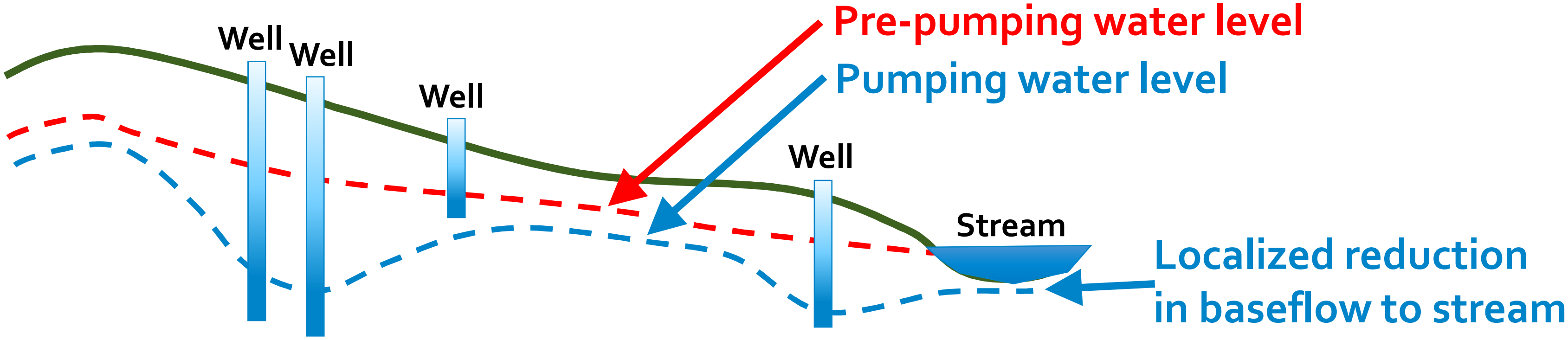
Hays, P.D., Knierim, K.J., Breaker, Brian, Westerman, D.A., and Clark, B.R., 2016, Hydrogeology and hydrologic conditions of the Ozark Plateaus aquifer system: USGS Scientific Investigations Report 2016–5137.

Groundwater Budgets

- Useful to compare **recharge** and **storage** to **demand**
  - Demand > recharge = net depletion from storage
- Precipitation is not only source of **recharge** to certain aquifers
  - Ozark Aquifer contributes a significant amount or recharge to alluvial aquifers
  - Pumping may induce recharge from surface water
  - Recharge from other sources difficult to estimate without detailed groundwater flow modeling
- Lateral and vertical flow between aquifers is not estimated

Groundwater Budgets – Limitations Due to Scale

- **Localized** withdrawals may be unsustainable
  - Impacts to nearby (shallower) wells may occur
  - May cause decline in water quality
  - May cause reduction to stream baseflow

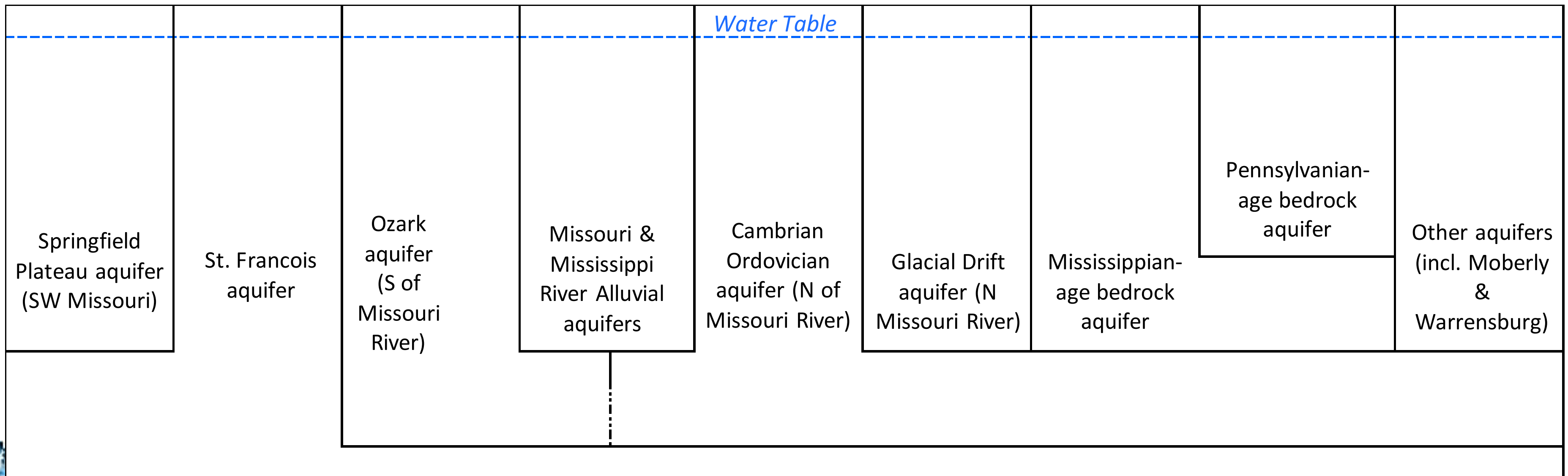


- Not all groundwater can be physically or economically extracted

MISSOURI WATER RESOURCES PLAN

Groundwater Budgets

Generalized Representation of Aquifers present in each HUC4



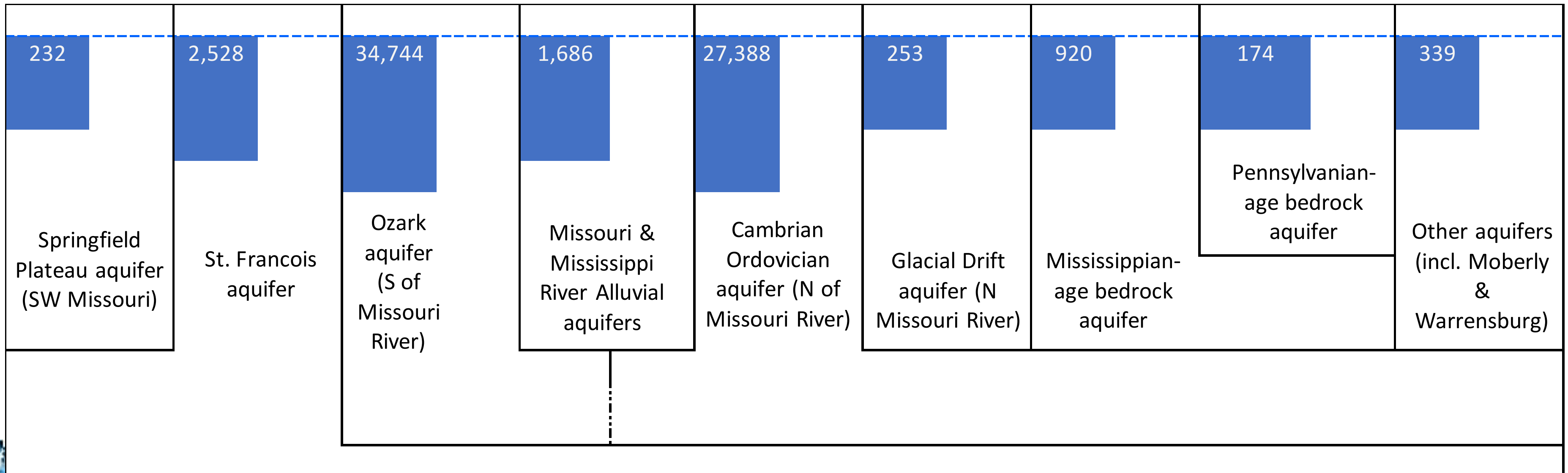
Lower Missouri
HUC4 - 1030

MISSOURI WATER RESOURCES PLAN

Groundwater Budgets – Storage

Potable groundwater storage in billion gallons (bg)

Source: MoDNR, 1997. Groundwater Resources of Missouri, Water Resources Report 46, Missouri State Water Plan Series, Vol II.

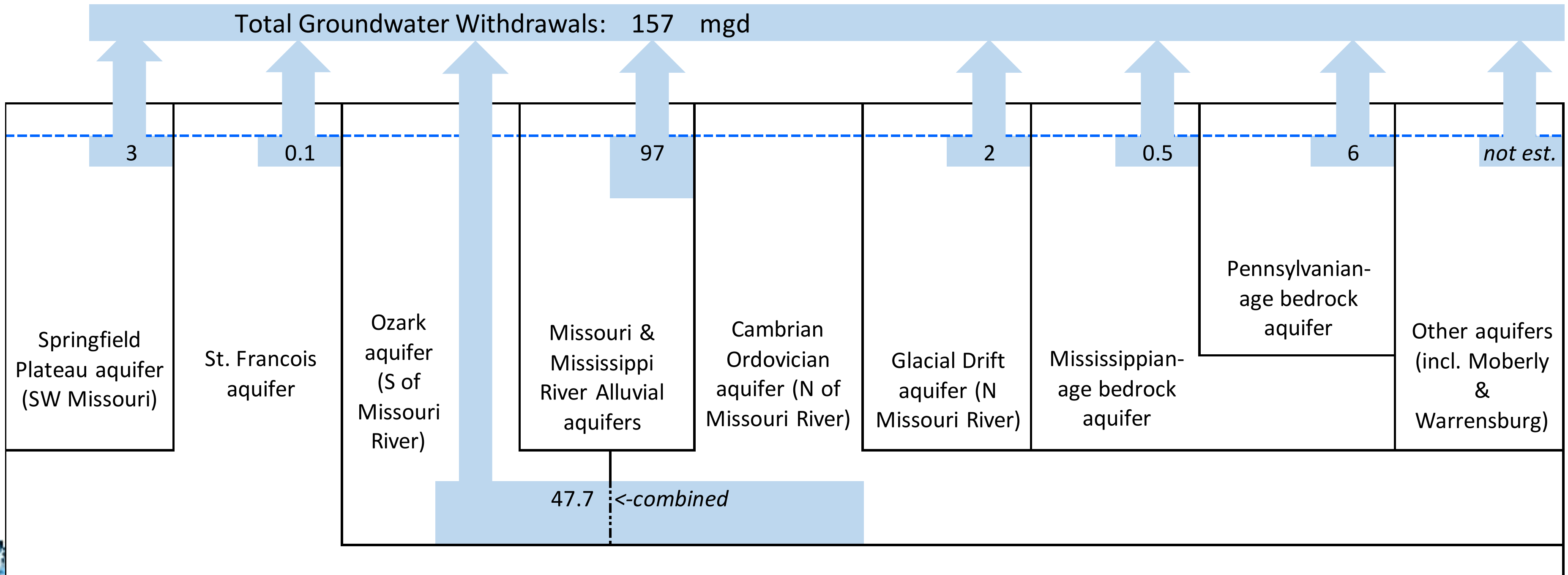


Lower Missouri
HUC4 - 1030

MISSOURI WATER RESOURCES PLAN

Groundwater Budgets – Demands

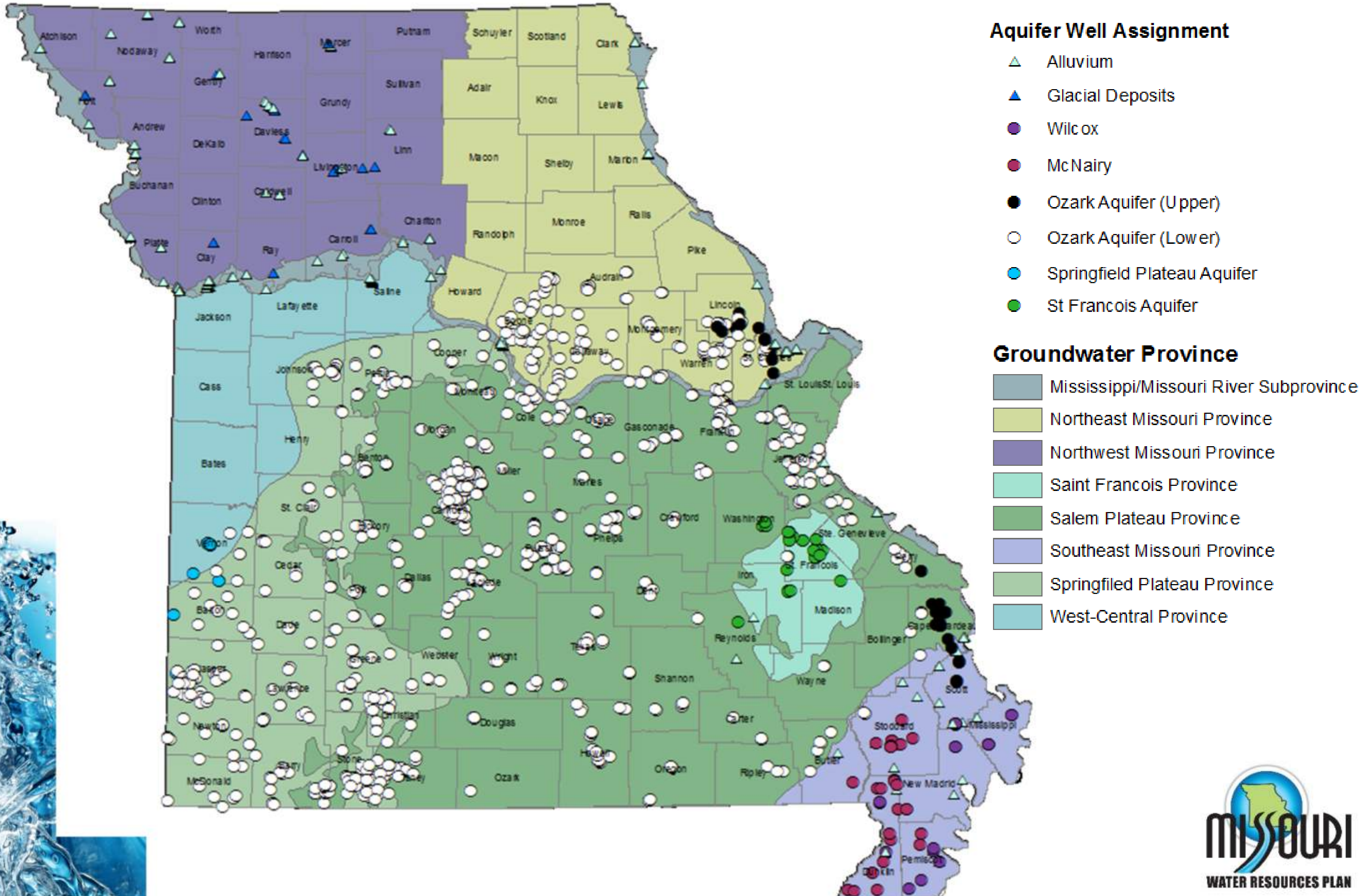
Groundwater withdrawals in million gallons per day (mgd)



Lower Missouri
HUC4 - 1030

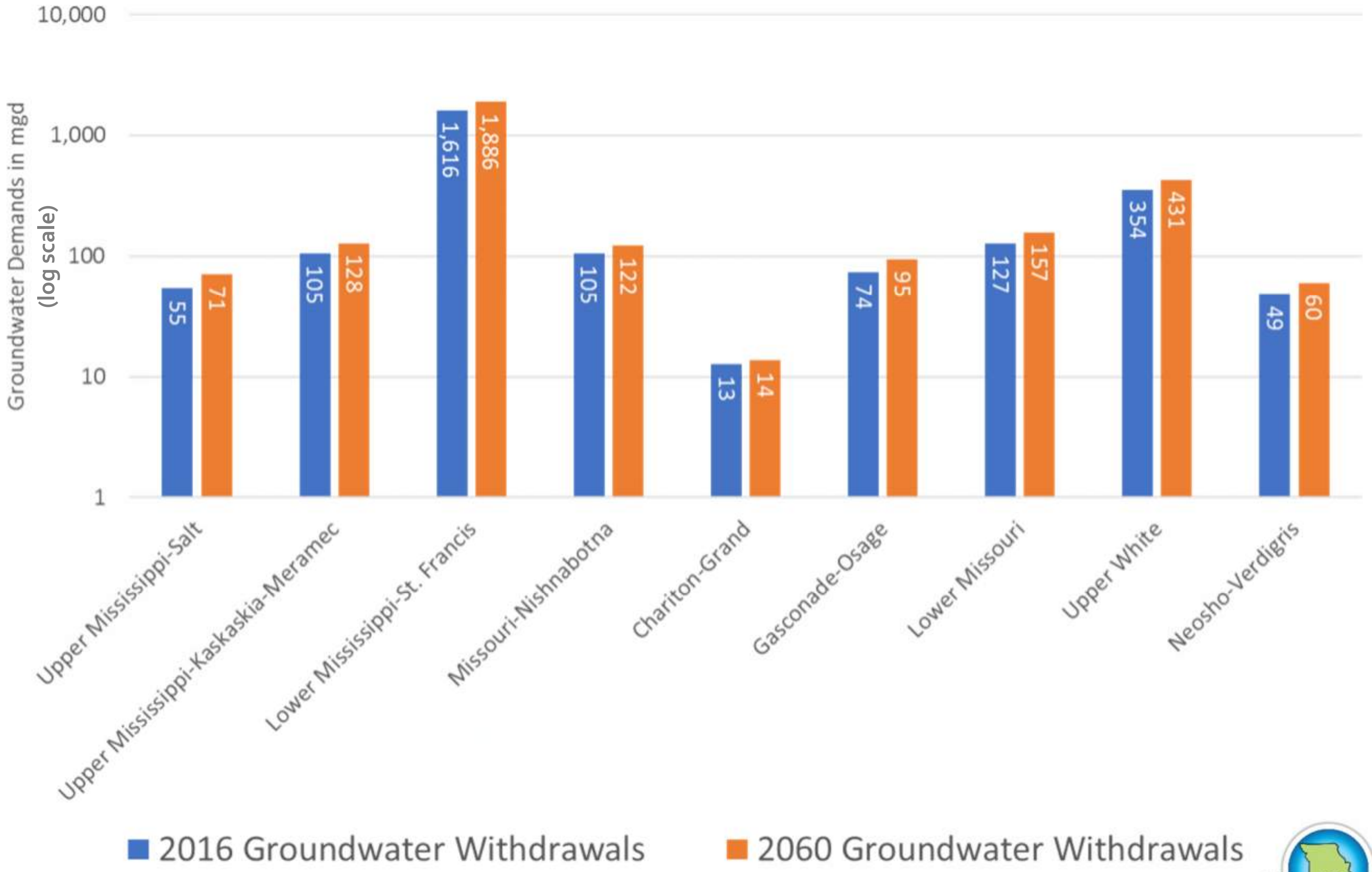
MISSOURI WATER RESOURCES PLAN

Groundwater Budgets – Demands



MISSOURI WATER RESOURCES PLAN

Comparison of 2016 and Projected 2060 Groundwater Demands by HUC4 Basin

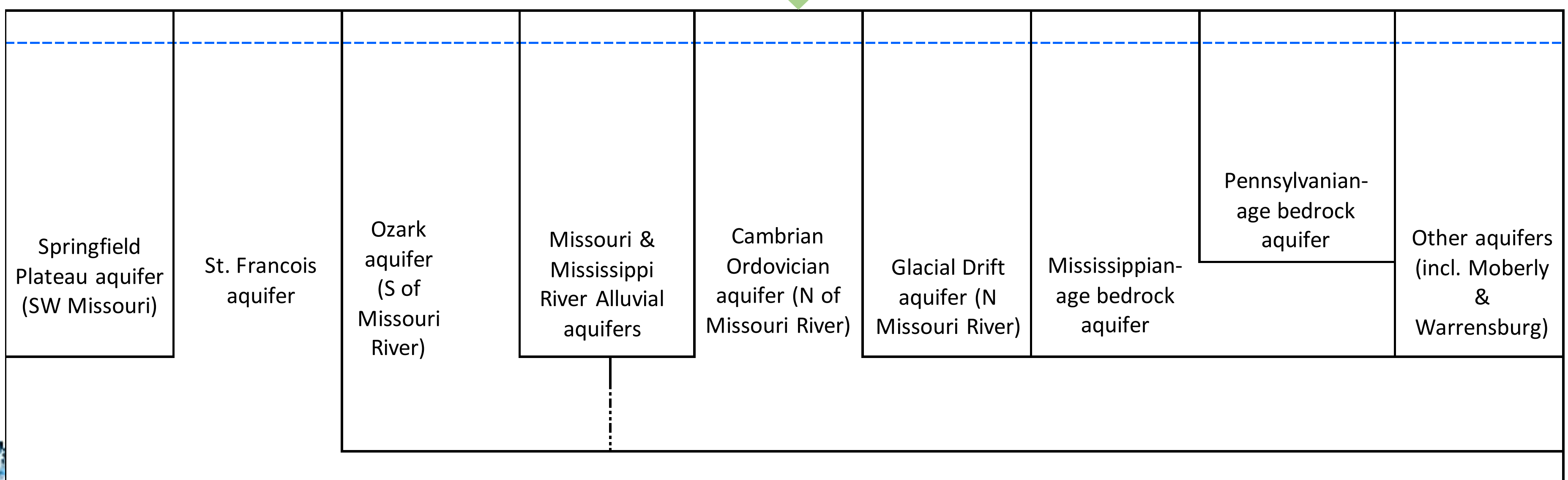


MISSOURI WATER RESOURCES PLAN

Groundwater Budgets – Recharge

Recharge to Water Table in million gallons per day (mgd)

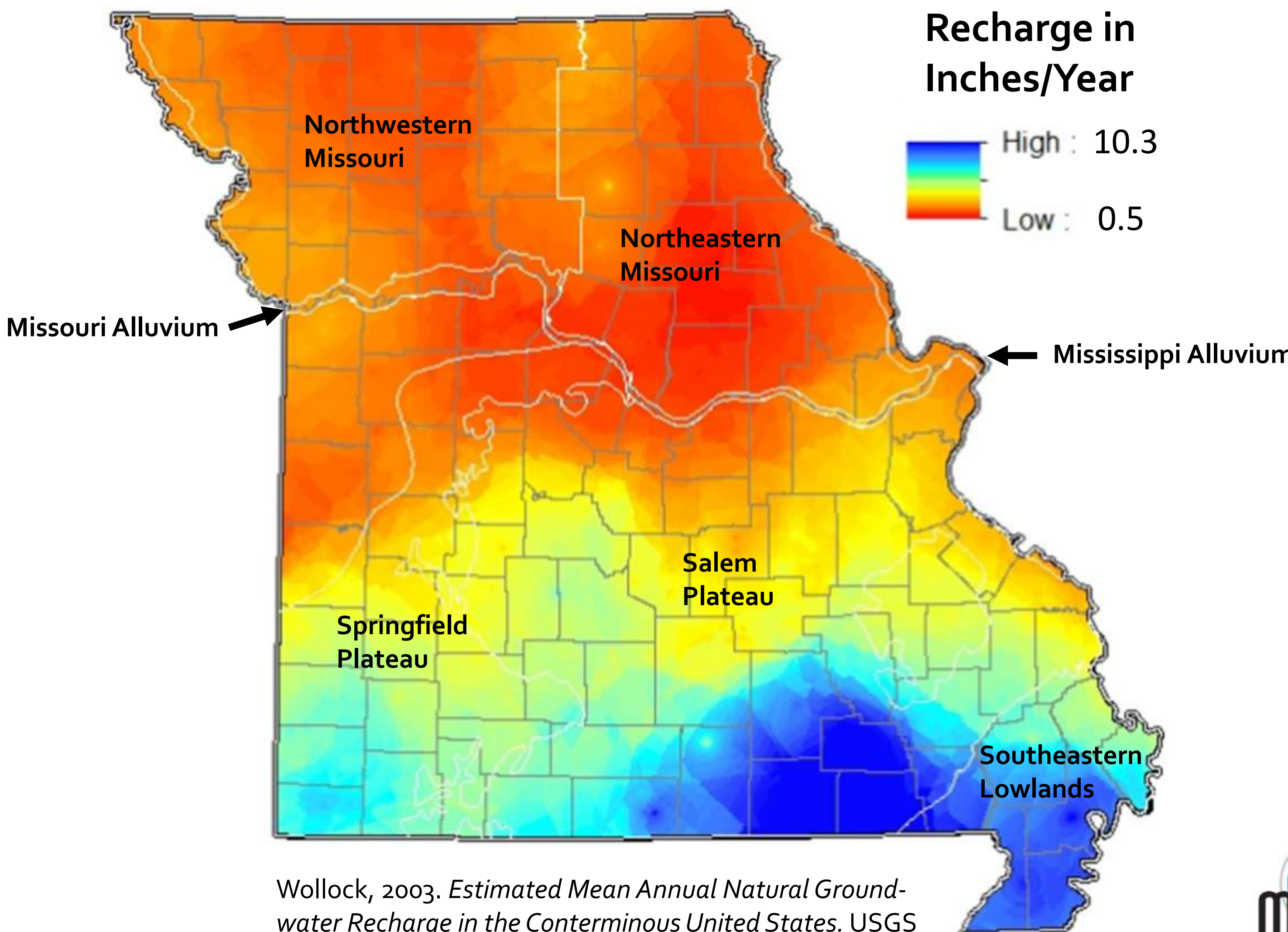
Recharge to Water Table from Precipitation: 581 mgd



Lower Missouri
HUC4 - 1030

WATER RESOURCES PLAN

USGS Estimated Mean Annual Recharge



Wollock, 2003. *Estimated Mean Annual Natural Ground-water Recharge in the Conterminous United States.* USGS Open File Report 03-311

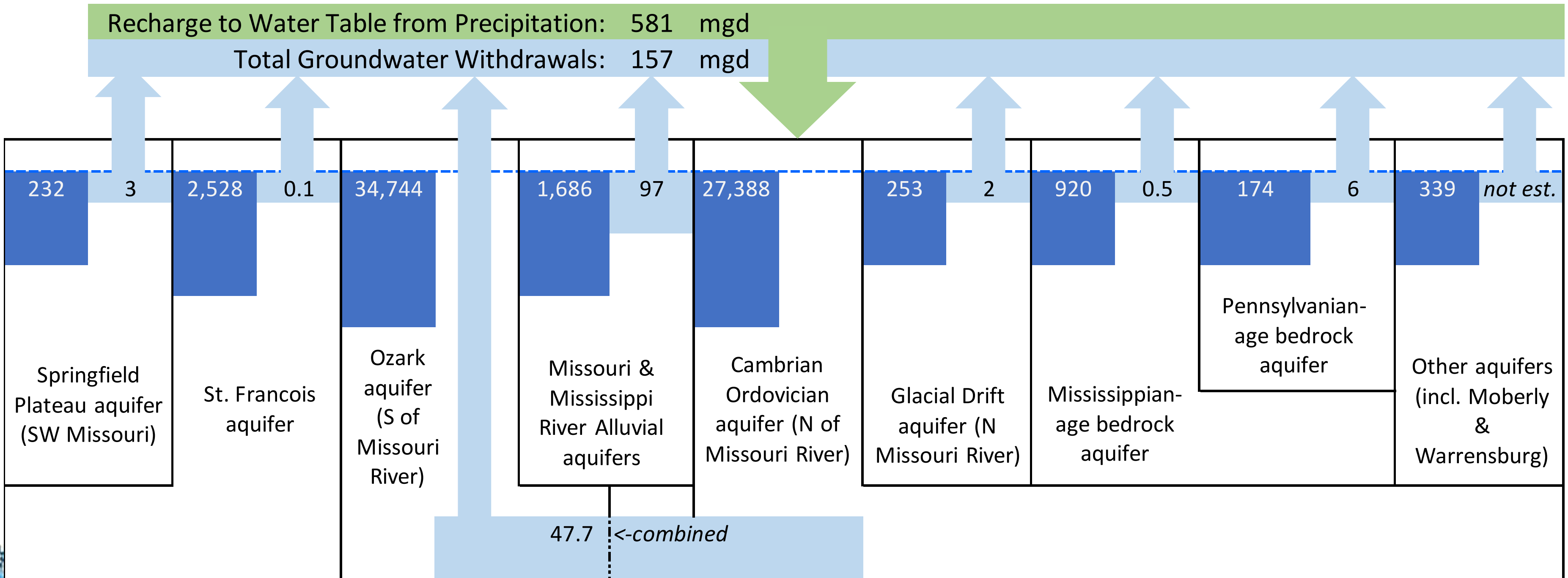
USGS Estimated Mean Annual Recharge

- 1-km resolution raster dataset of mean annual natural ground-water recharge derived from 1951-80 mean annual runoff contour map and baseflow index (BFI).
- BFI estimated by stream hydrograph separation method
- Assumes that:
  1. Long-term average natural ground-water recharge is equal to long-term average natural ground-water discharge to streams, and
  2. The base-flow index reasonably represents, over the long term, the percentage of natural ground-water discharge in streamflow.

Groundwater Budgets – Average Conditions

Groundwater withdrawals are shown in million gallons per day (mgd)
Potable groundwater storage is shown in billion gallons (bg)

2060 Demands



Precipitation: 20,299 mgd
Evapotranspiration: 12,055 mgd
Recharge to Water Table from Precipitation: 581 mgd

Total Potable Groundwater Storage: 68,263 bg
Total Groundwater Withdrawals: 157 mgd
Increase in Withdrawals from 2016: 31 mgd
Withdrawals as a Percent of Recharge: 27%

Lower Missouri
HUC4 - 1030

Groundwater Budgets – Average Conditions

Groundwater withdrawals are shown in million gallons per day (mgd)
Potable groundwater storage is shown in billion gallons (bg)

2060 Demands

Recharge to Water Table from Precipitation: 514 mgd
Total Groundwater Withdrawals: 14 mgd

Aquifer	Storage (bg)	Withdrawals (mgd)
Missouri & Mississippi River Alluvial aquifers	353	7
Glacial Drift aquifer (N Missouri River)	6,120	3
Cambrian Ordovician aquifer (N of Missouri River)	12	0.002
Mississippian-age bedrock aquifer	1.2	0.0008
Pennsylvanian-age bedrock aquifer	*not est.*	4
Other aquifers (incl. Moberly & Warrensburg)	3	*not est.*

Precipitation:	15,242	mgd
Evapotranspiration:	9,020	mgd
Recharge to Water Table from Precipitation:	514	mgd

Total Potable Groundwater Storage:	6,490	bg
Total Groundwater Withdrawals:	14	mgd
Increase in Withdrawals from 2016:	1	mgd
Withdrawals as a Percent of Recharge:	3%	

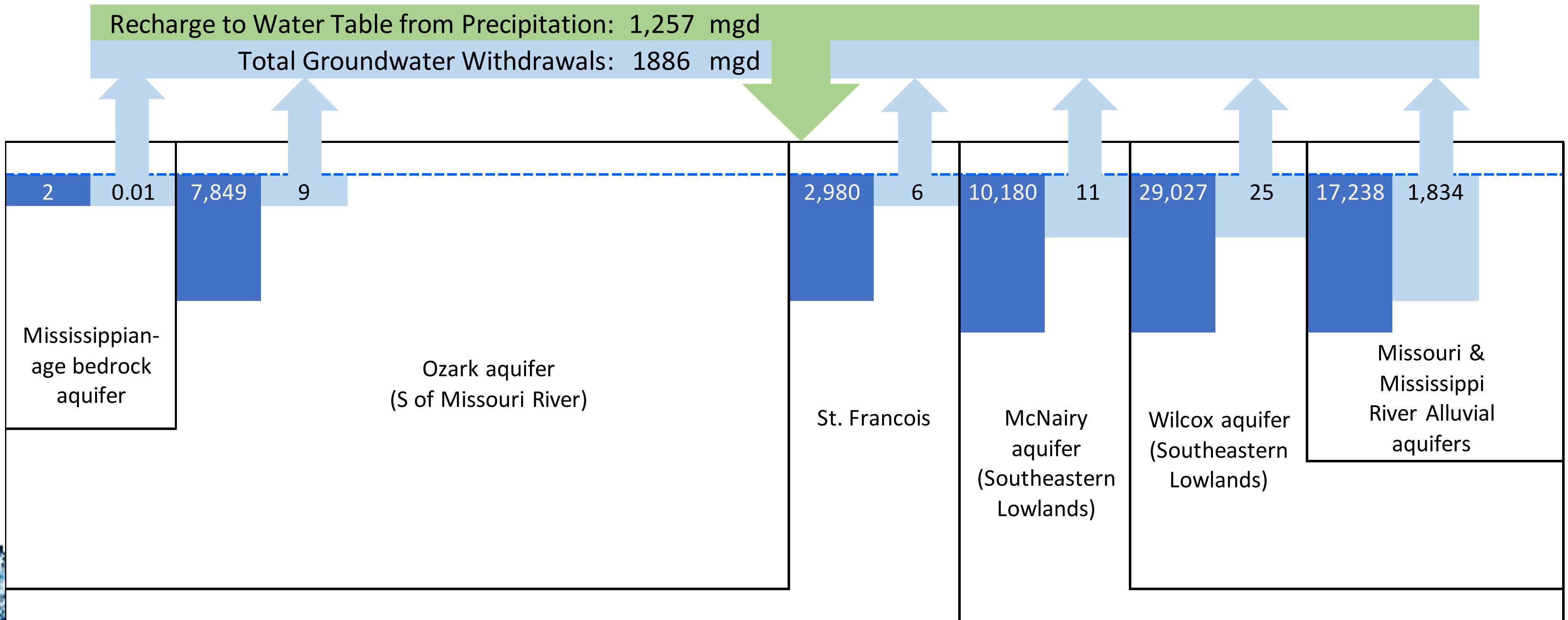
Chariton-Grand
HUC4 - 1028

MISSOURI WATER RESOURCES PLAN

Groundwater Budgets – Average Conditions

Groundwater withdrawals are shown in million gallons per day (mgd)
Potable groundwater storage is shown in billion gallons (bg)

2060 Demands



Precipitation: 10,869 mgd
Evapotranspiration: 5,761 mgd
Recharge to Water Table from Precipitation: 1,257 mgd

Total Potable Groundwater Storage: 67,277 bg
Total Groundwater Withdrawals: 1886 mgd
Increase in Withdrawals from 2016: 270 mgd
Withdrawals as a Percent of Recharge: 150%

Lower Mississippi-St. Francis HUC4 - 802

MISSOURI WATER RESOURCES PLAN

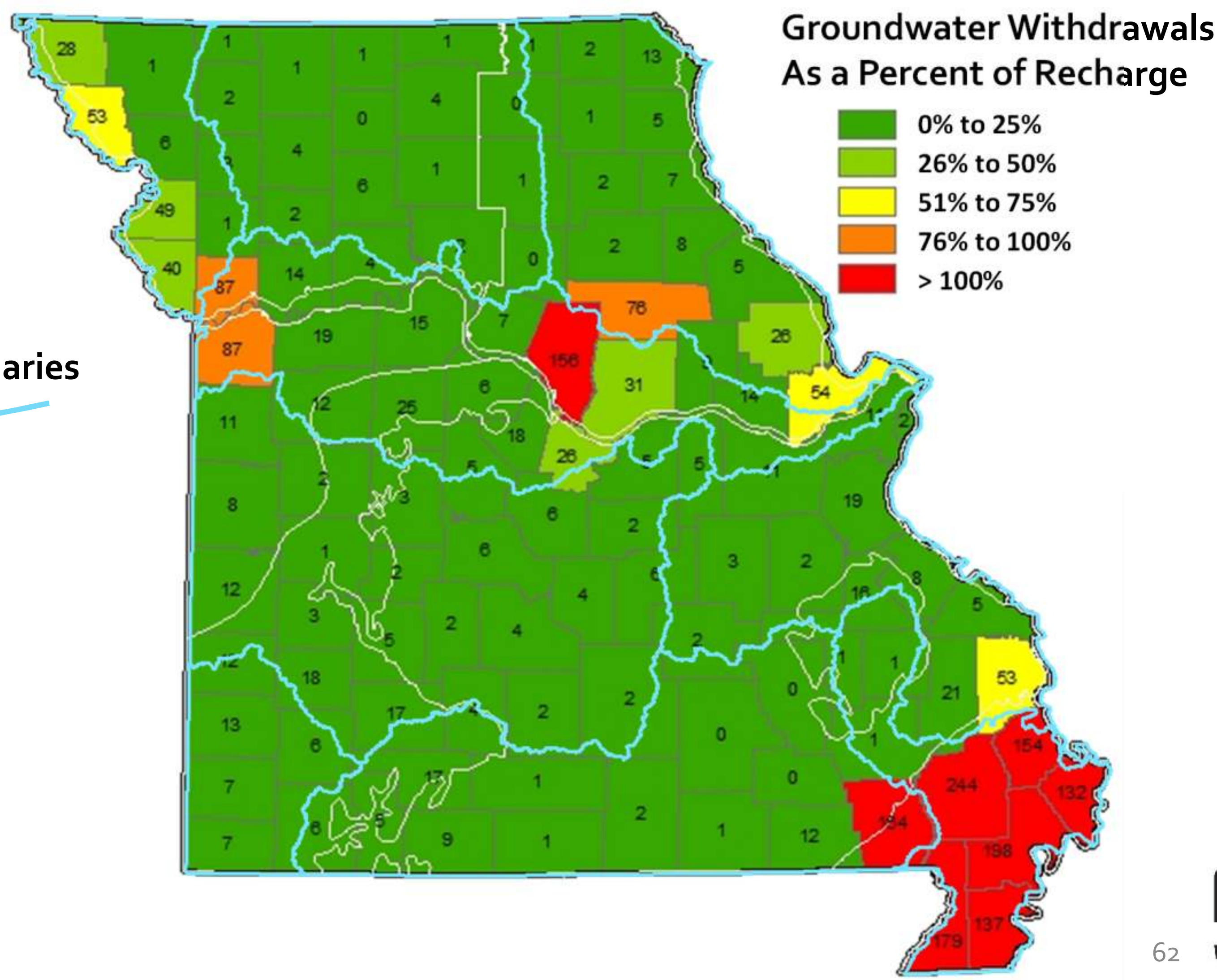
Groundwater Budget Summary by HUC4

HUC4	Basin Name	Total Potable Groundwater Storage *(billion gals)*	Recharge to Water Table from Precipitation *(mgd)*	Total 2060 Groundwater Withdrawals *(mgd)*	Withdrawals as a Percent of Recharge *(%)*
711	Upper Mississippi-Salt	26,896	406	71	17%
714	Upper Mississippi-Kaskaskia-Meramec	42,985	964	128	13%
802	Lower Mississippi-St. Francis	67,277	1,257	1,886	150%
1024	Missouri-Nishnabotna	3,627	280	122	44%
1028	Chariton-Grand	6,490	514	14	3%
1029	Gasconade-Osage	140,732	1,905	95	5%
1030	Lower Missouri	68,263	581	157	27%
1101	Upper White	108,451	2,977	431	14%
1107	Neosho-Verdigris	30,974	650	60	9%

2060 Groundwater Withdrawals as a Percentage of Estimated Recharge to Water Table

(Includes Alluvial Aquifer Demands)

HUC4 Boundaries



MISSOURI WATER RESOURCES PLAN

Potable Groundwater Storage

In Production Regions and Aquifers

Missouri & Mississippi River Alluvium*

3,927 bg

Glacial Drift & Alluvium

9,184 bg

Ordovician and Cambrian Dolomites & Sandstones

379,917 bg

Freshwater-Saltwater Transition Zone

Storage in billion gallons

Pennsylvanian and Mississippian Limestones and Sandstones

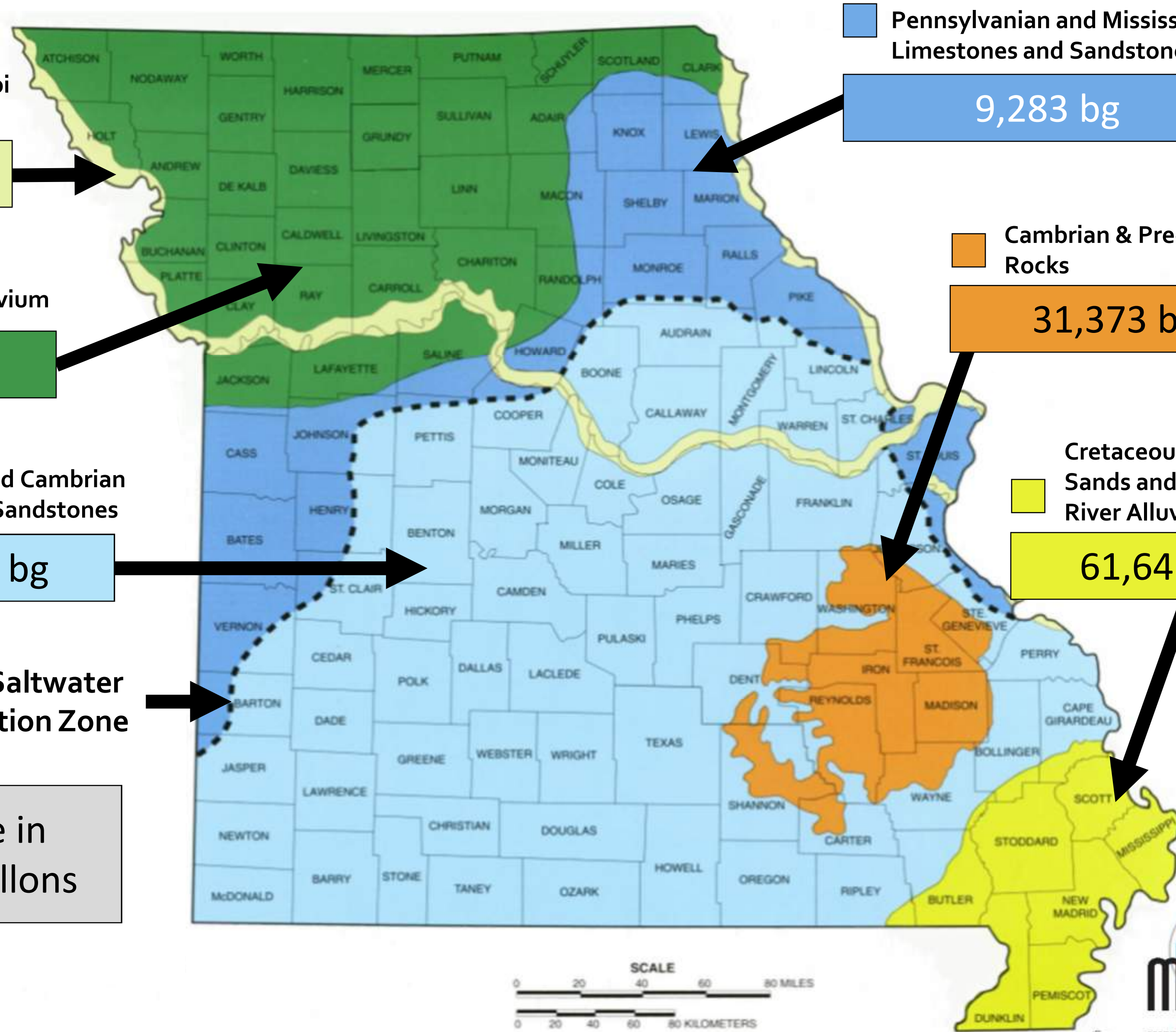
9,283 bg

Cambrian & Precambrian Rocks

31,373 bg

Cretaceous & Tertiary Sands and Mississippi River Alluvium

61,641 bg

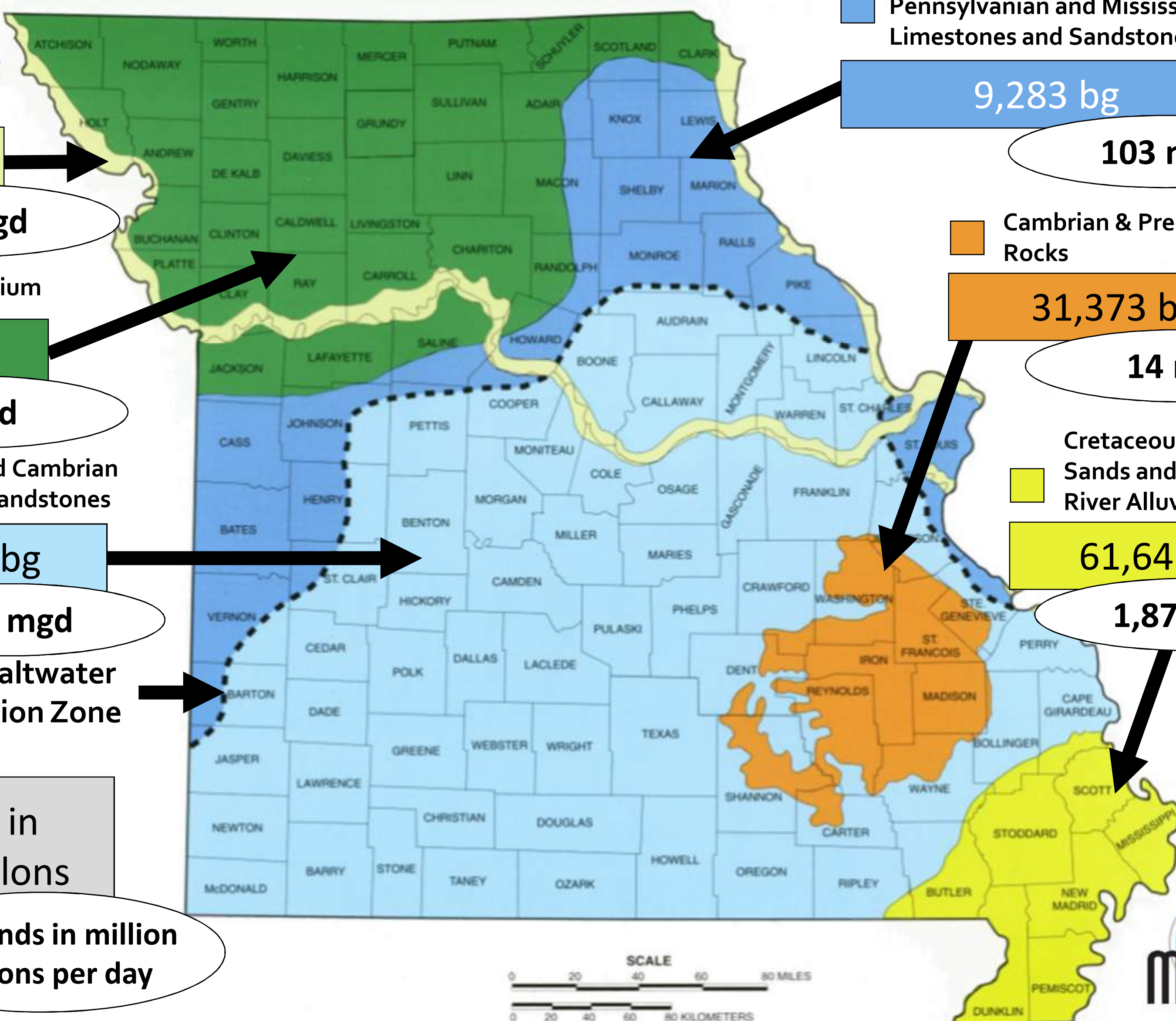


* Not including Mississippi River Alluvium in the SE Lowlands

MISSOURI WATER RESOURCES PLAN

Potable Groundwater Storage & 2060 Demands

In Production Regions and Aquifers



Missouri & Mississippi River Alluvium*

3,927 bg

647 mgd

Glacial Drift & Alluvium

9,184 bg

8 mgd

Ordovician and Cambrian Dolomites & Sandstones

379,917 bg

319 mgd

Freshwater-Saltwater Transition Zone

Pennsylvanian and Mississippian Limestones and Sandstones

9,283 bg

103 mgd

Cambrian & Precambrian Rocks

31,373 bg

14 mgd

Cretaceous & Tertiary Sands and Mississippi River Alluvium

61,641 bg

1,871 mgd

Storage in billion gallons

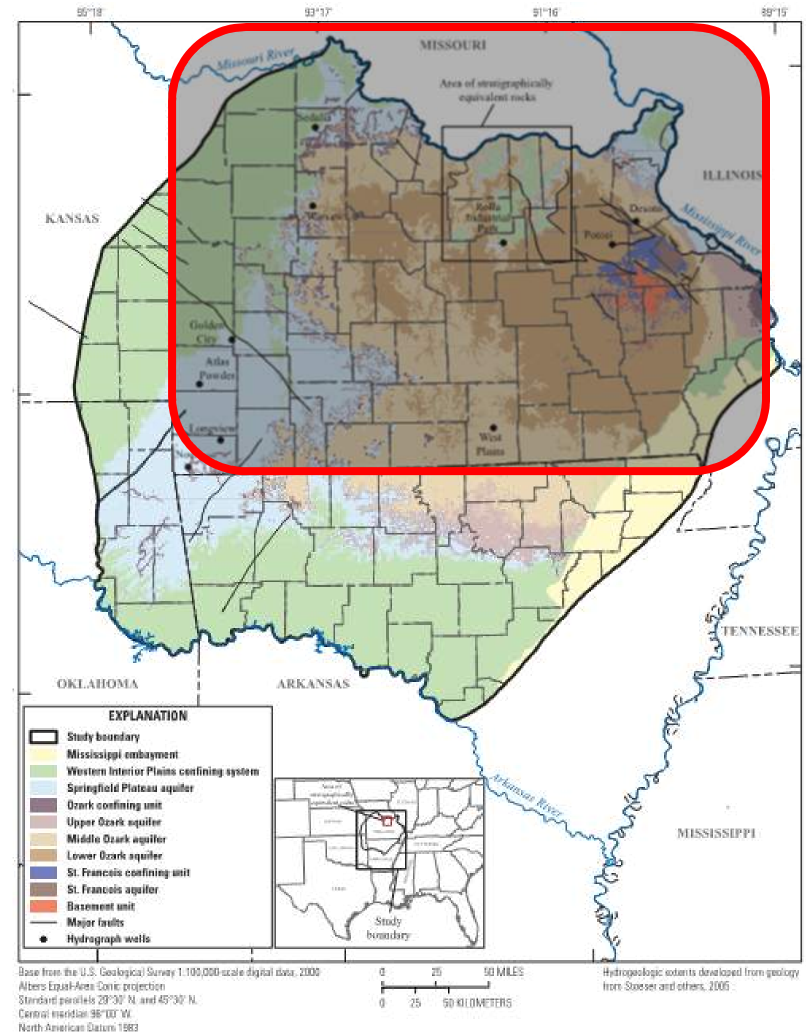
Demands in million gallons per day

MISSOURI WATER RESOURCES PLAN

* Not including Mississippi River Alluvium in the SE Lowlands

Groundwater Model Update

- The Ozark Plateaus Regional Aquifer Study – USGS SRI 2018-5035
- Obtained model files
- Reviewing and correlating wells and pumping data
- Preparing MODFLOW files with projected groundwater withdrawals

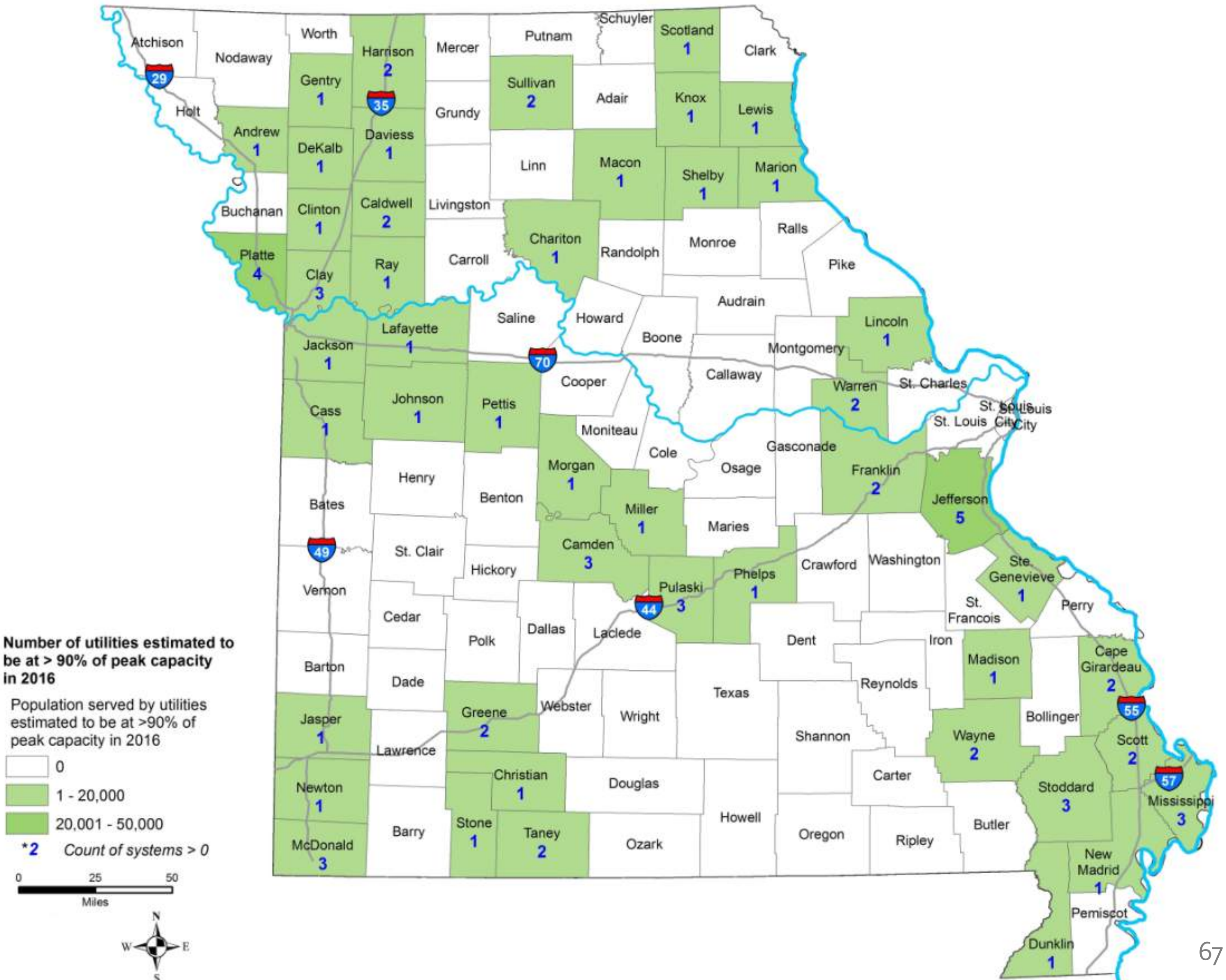


MISSOURI WATER RESOURCES PLAN

Infrastructure Update

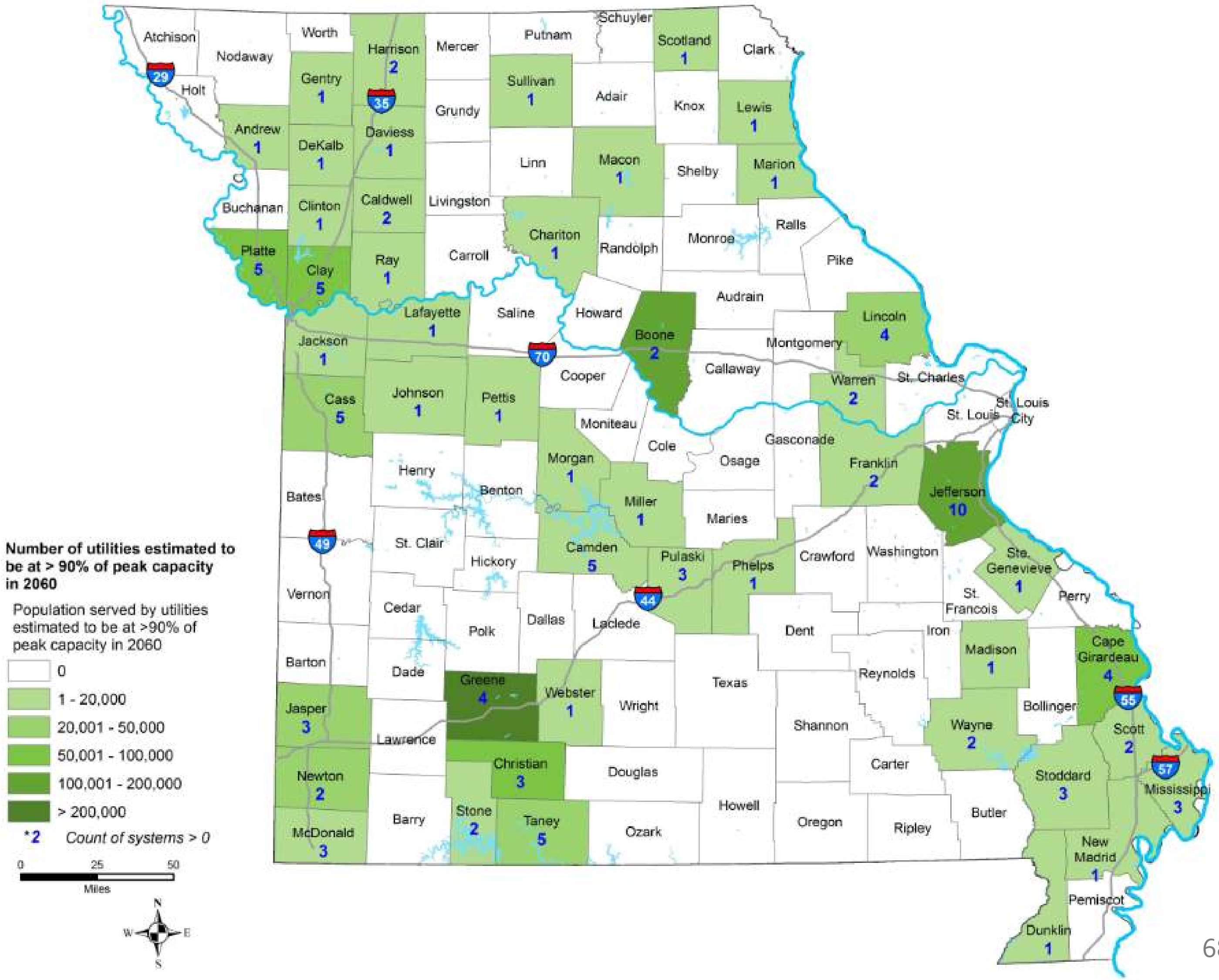
Demand-Driven Growth

Drinking Water Treatment Peak Capacity 2016



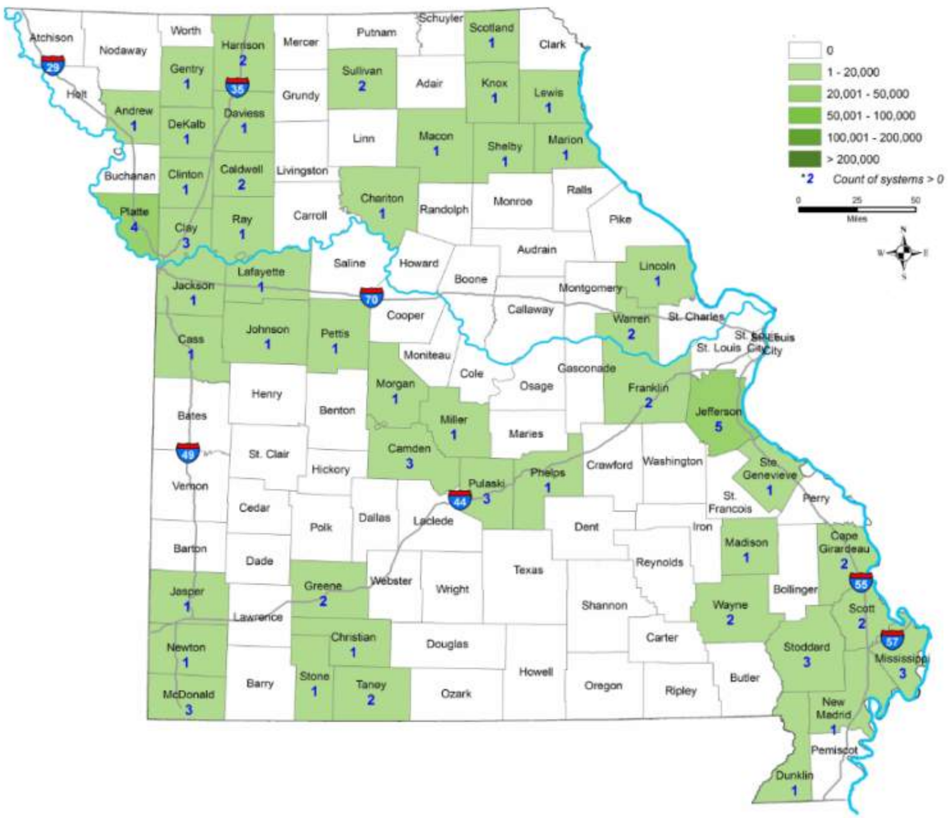
Demand-Driven Growth

Drinking Water Treatment Peak Capacity 2060

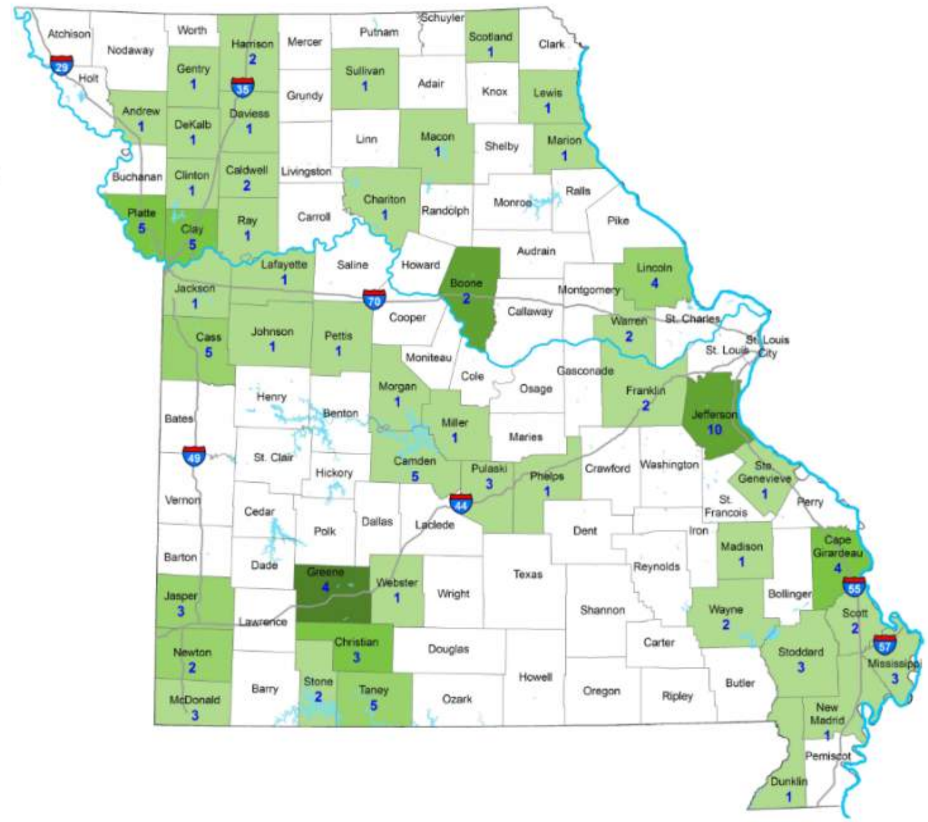


Demand-Driven Growth

Drinking Water Treatment Peak Capacity 2016 versus 2060



2016



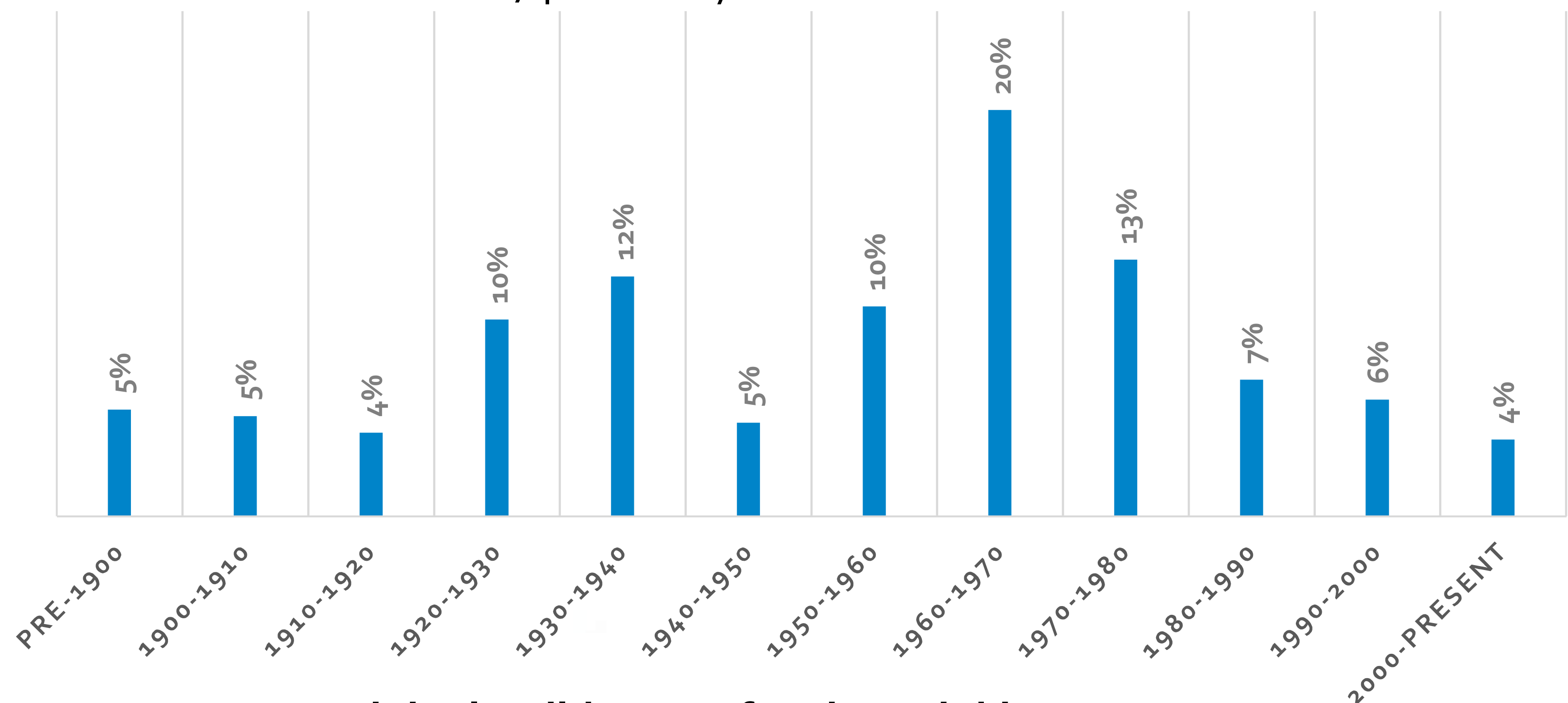
2060

MISSOURI WATER RESOURCES PLAN

Missouri Drinking Water Pipe Replacement and Age of Systems

Average Nationwide Drinking Water Pipe Replacement Rate: 0.5 percent /year

- Kansas City: 1 percent /year
- St Louis: 0.5 percent /year
- MO American Water: 0.7 percent /year



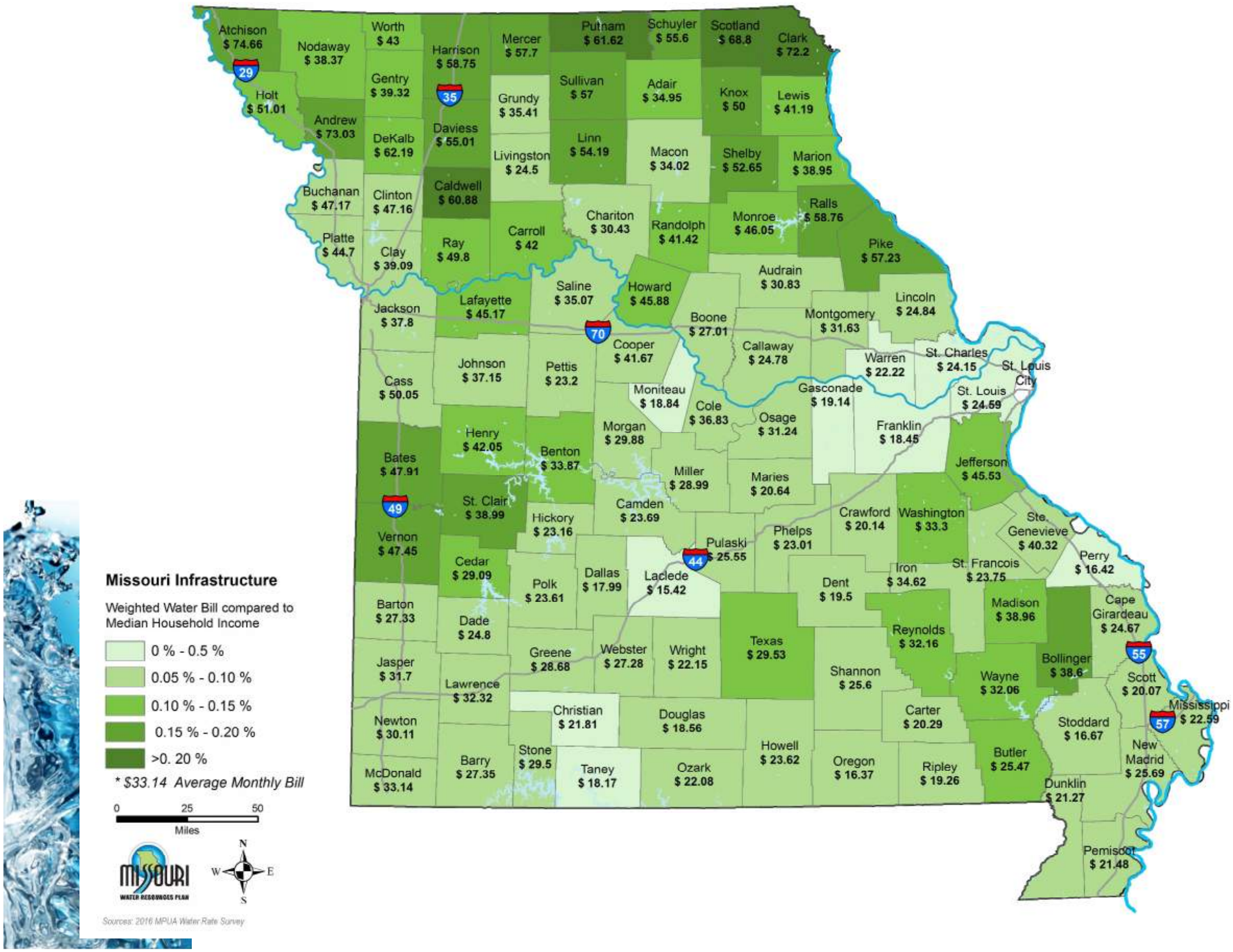
Original Build Date of Major Drinking Water Systems in Missouri

Source: SDWIS

MISSOURI WATER RESOURCES PLAN

70

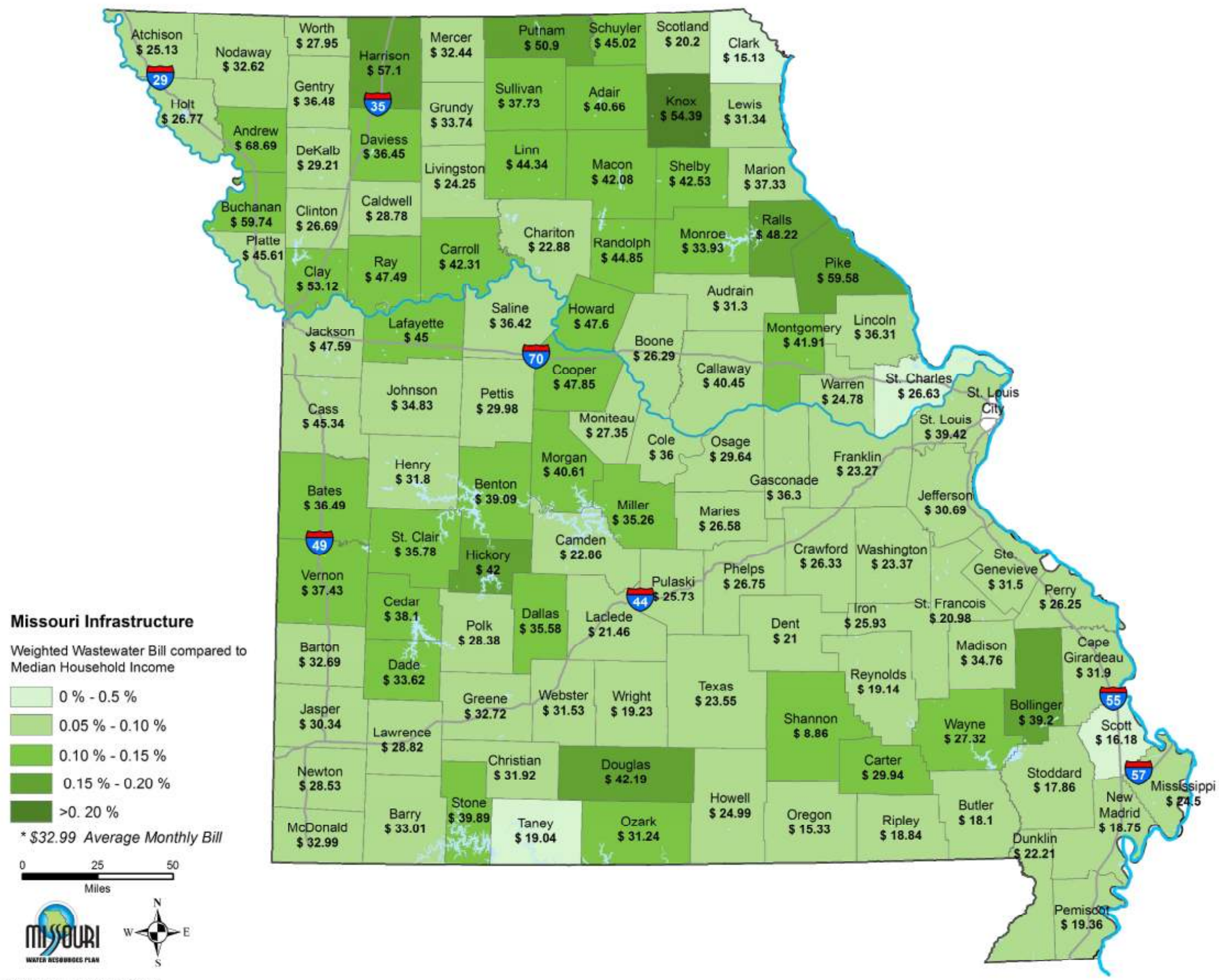
Average Missouri Drinking Water Rates
(Reported to MPUA)



MISSOURI WATER RESOURCES PLAN

Average Missouri Wastewater Rates

(Reported to MPUA)



MISSOURI WATER RESOURCES PLAN

Major Water Infrastructure Projects

Blacksnake Creek Stormwater Separation

KC Water/WW Improvements (~400M)

St Charles 12” Main Replacement (4M)

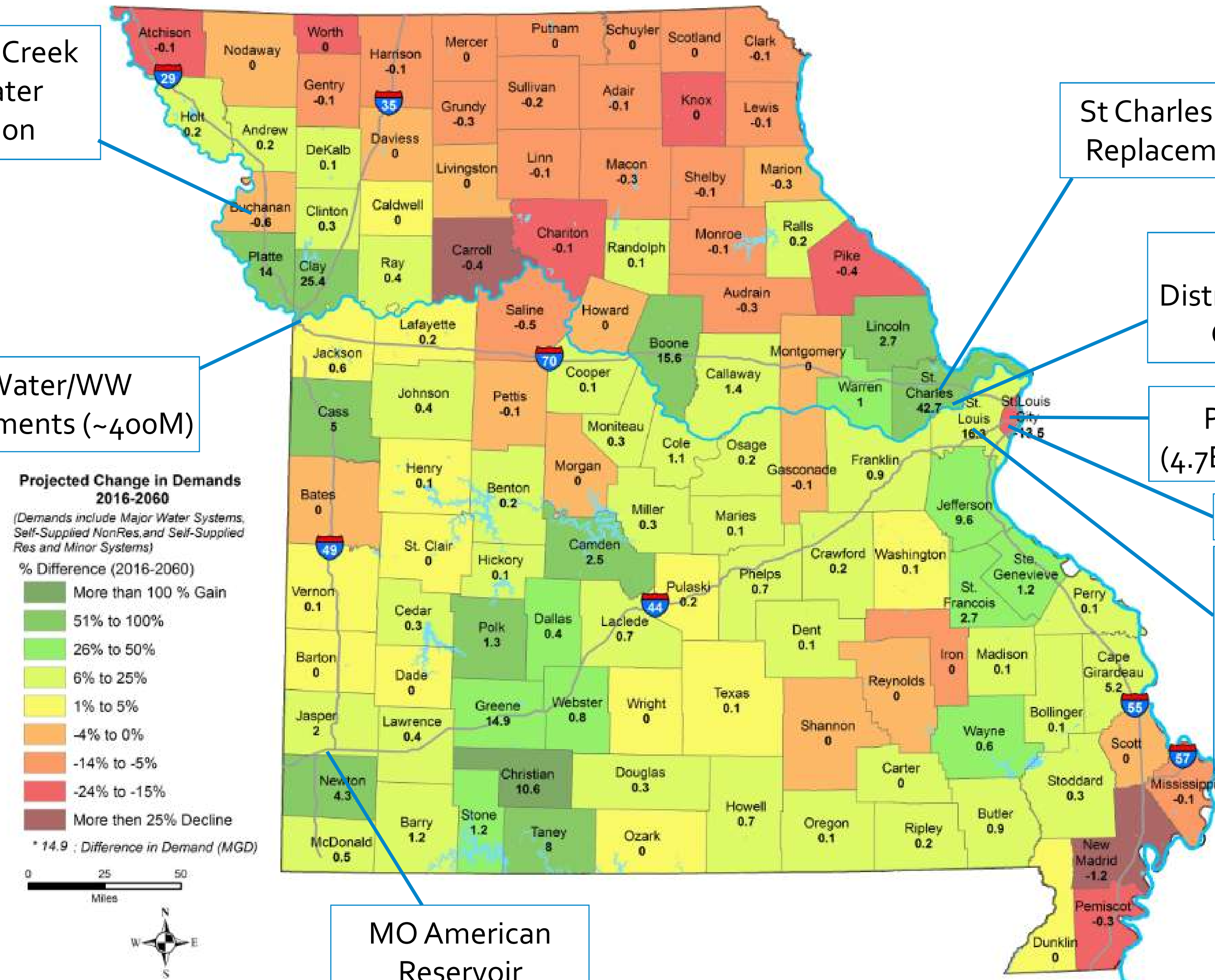
O’Fallon Distribution System CIP (>100M)

Project Clear (4.7B over 23 years)

Deer Creek (88M)

- Gravois Trunk Sanitary Storage Facility
- Lower & Middle River Des Peres Storage Tunnel

MO American Reservoir



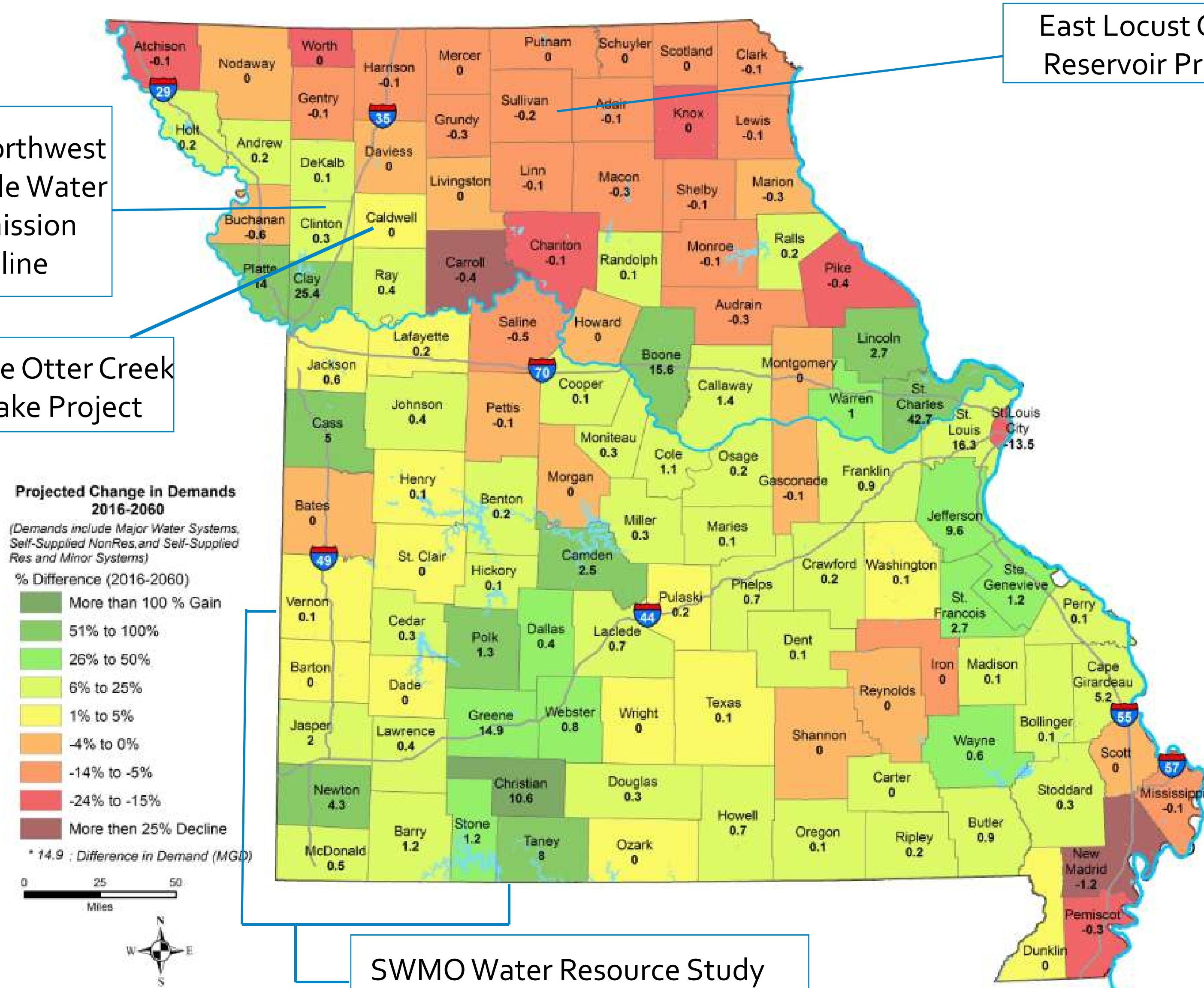
MISSOURI WATER RESOURCES PLAN

Regional Water Infrastructure Projects

East Locust Creek Reservoir Project

Great Northwest Wholesale Water Commission Pipeline

Little Otter Creek Lake Project



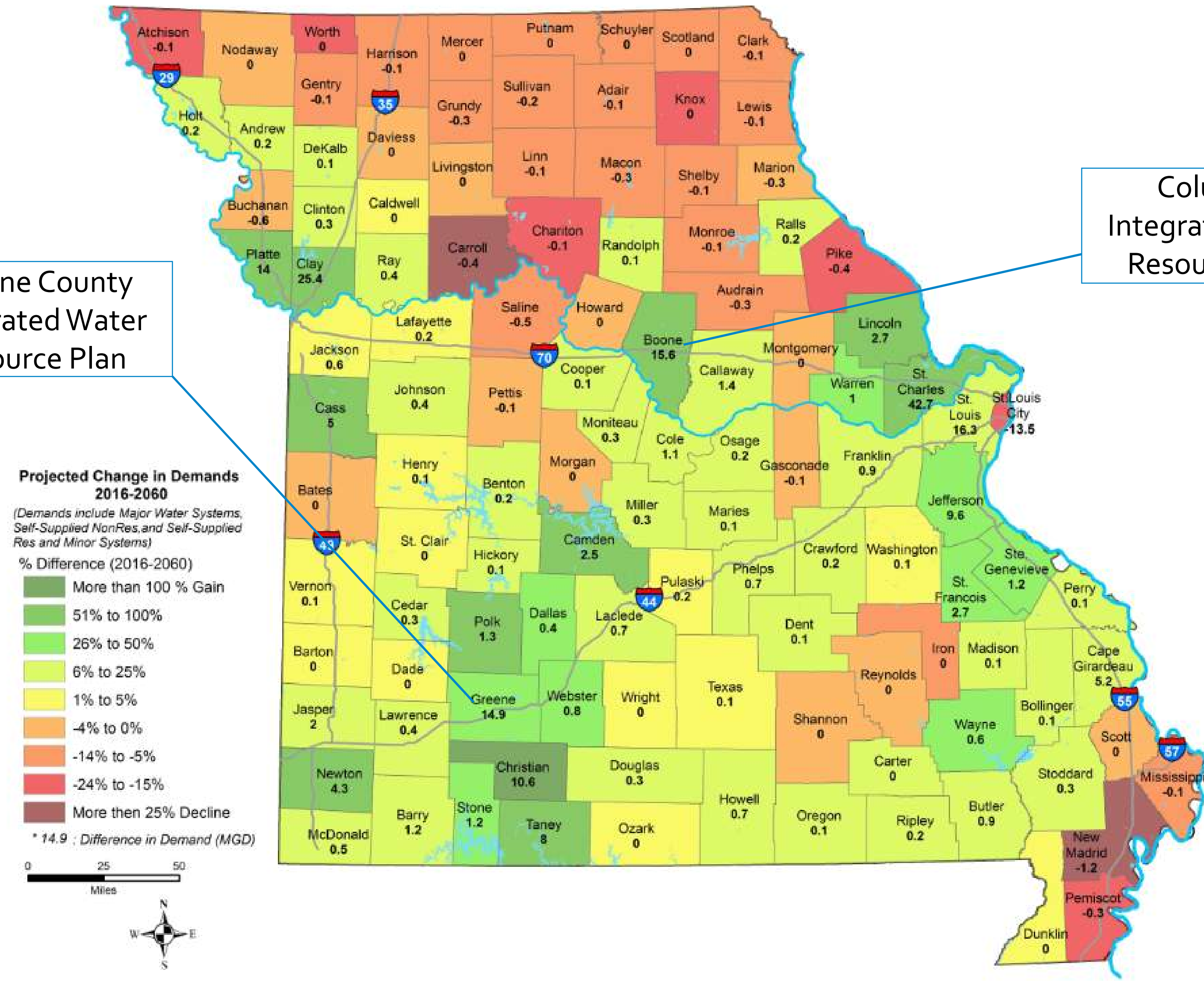
SWMO Water Resource Study

MISSOURI WATER RESOURCES PLAN

Integrated Water Resource Planning

Greene County Integrated Water Resource Plan

Columbia Integrated Water Resource Plan



MISSOURI WATER RESOURCES PLAN

Thank You